Balance of Plant
Requirements and Concepts
for Tokamak Reactors

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Introduction

A Power Plant can be divided into:

- **The Steam Supply System (thermal heat source)**
- **Balance of Plant Systems (BoP) (systems for power conversion and distribution)**

BoP Objectives

- Efficient conversion of thermal power to electricity
- Reliable electricity supply for its own components
- Minimum contribution to the overall plant costs
- High availability of systems and components
- Reliable and effective operation of auxiliary systems

References

- Designs of existing conventional and fission power plants
- SEAFP Studies
- Power Plant Conceptual Study (PPCS)

Objectives of the PPCS

The Study has to demonstrate:

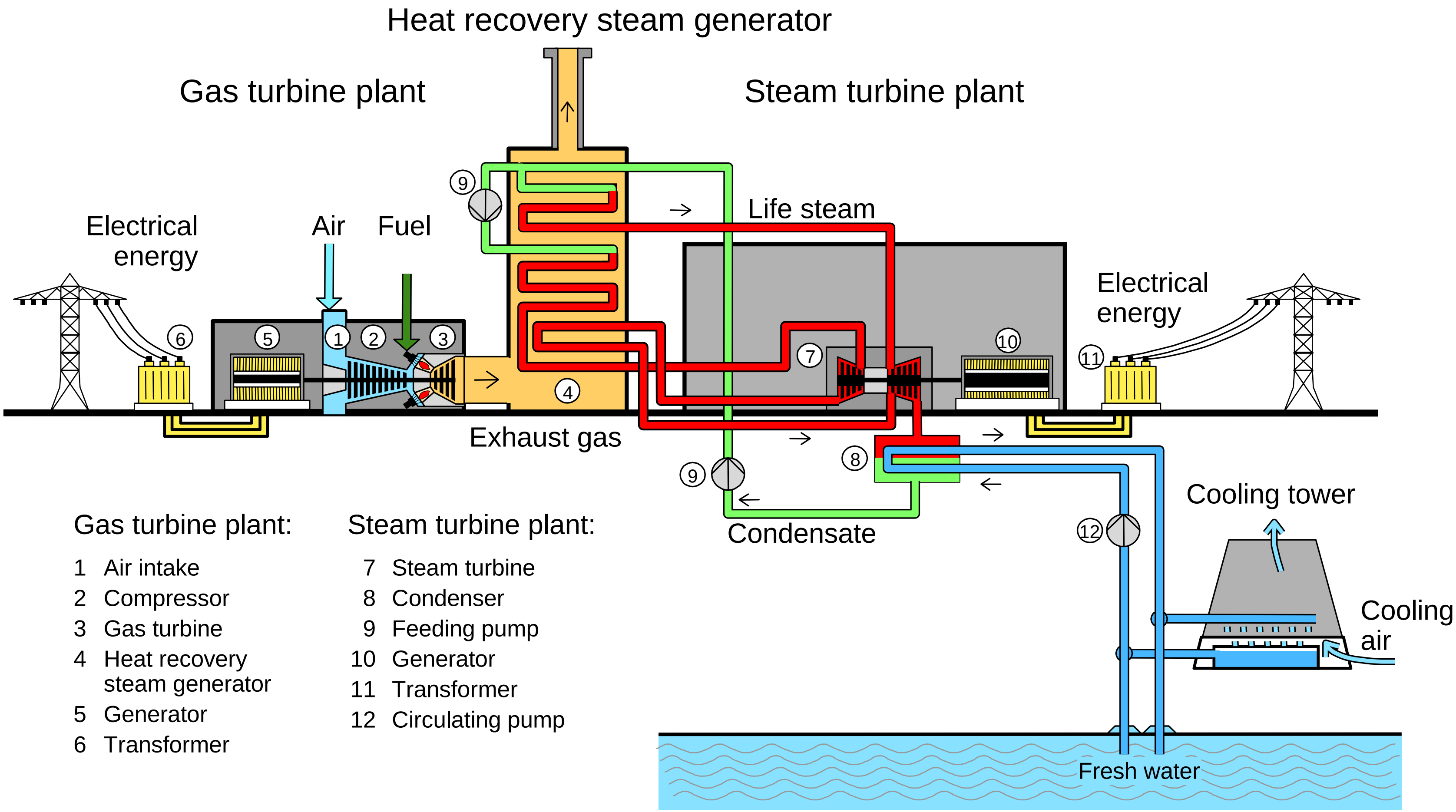
- The credibility of the power plant design(s)
- The claims for the safety and environmental advantages and for the economic viability of fusion power
- The robustness of the analyses and conclusions

➔ *also relevant for the BoP Systems*

Conventional Plants

- Boiler
- Heat transfer and conversion system incl. auxiliary systems

Schematic of a Combined Cycle Multi-Shaft Power Plant



Gas turbine plant:

1 Air intake
2 Compressor
3 Gas turbine
4 Heat recovery steam generator
5 Generator
6 Transformer

Steam turbine plant:

7 Steam turbine
8 Condenser
9 Feeding pump
10 Generator
11 Transformer
12 Circulating pump

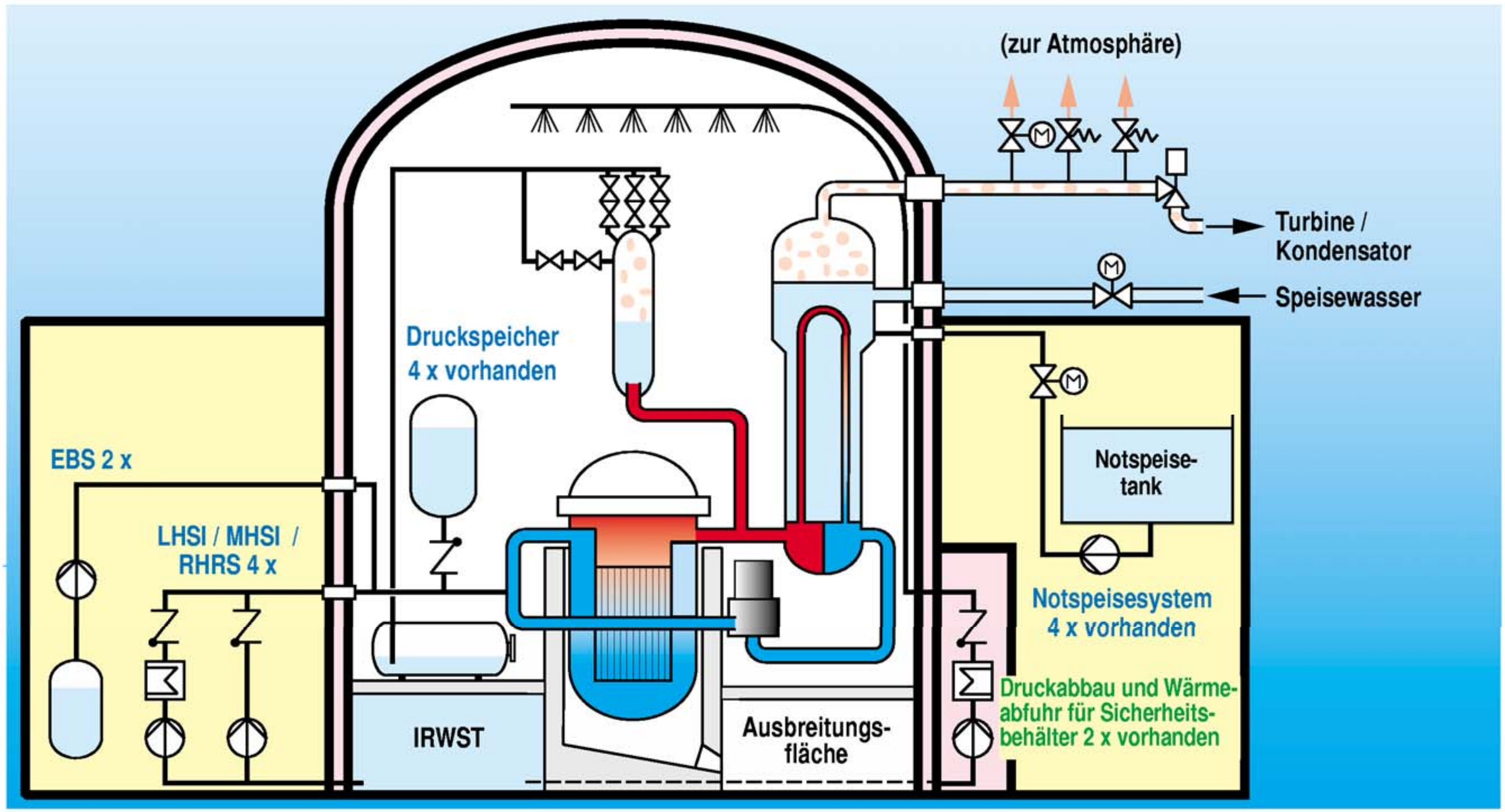
Fission Power Plants

Nuclear Fission Plants

- Nuclear Steam Supply System (NSSS) (fission core, water/He/LM coolant)

- Heat transfer and conversion system incl. auxiliary systems

EPR Layout



(zur Atmosphäre)
Turbine /
Kondensator
Speisewasser
Druckspeicher
4 x vorhanden
EBS 2 x
LHSI / MHSI /
RHRS 4 x
Notspeise-
tank
Notspeisesystem
4 x vorhanden
Druckabbau und Wärme-
abfuhr für Sicherheits-
behälter 2 x vorhanden
IRWST
Ausbreitungs-
fläche

Fusion Power Plants

Nuclear Fusion Plants (Tokamak-Type)

- Tokamak core (fusion plasma)
  - Confinement systems
  - Plasma Heating systems
  - Primary cooling system (water, helium, Pb - 17Li coolants)
- Heat transfer and conversion system incl. auxiliary systems

Important Systems and Components of the NSSS

- Reactor/tokamak core
- Reactor/vacuum vessel with all internals
- Primary loop (pumps, intermediate heat exchangers)
- DHR system
- Primary auxiliary systems
- Primary leak collection and leak detection systems
- Fire fighting systems for Primary Systems
- Core element handling
- Component handling
- Reactor protection system
- Reactor-specific instrumentation and control systems

Important Systems and Components of the BoP

- Buildings
- Steam and power conversion system
- Cooling water systems
- Auxiliary systems (e.g. auxiliary steam, hot water/cold water, demineralized water, compressed air)
- Ventilation systems
- Fire fighting systems for conventional fires
- Chemical water treatment
- Elevators and hoists
- Locks and gates
- Treatment of radioactive waste
- Plant and building drainage
- Systems for the electrical auxiliary power supply
- Non reactor-specific instrumentation and control systems

Strategy for a Fusion Power Plant

To find a niche in the existing world of electricity producing power plants it is necessary to have:

- Competitive construction and electricity production costs
- Comparable availability

The BoP systems have to provide a contribution to these requirements!

Requirements for Fusion Power Plants

- Base-load electricity production
- Steady-state operation
- Load-following capabilities
- Electrical power output equivalent to present LWR
- Easy maintenance
- Low recirculating power fraction

List of typical BoP Systems for a Tokamak Fusion Power Plant

- Secondary Heat Transport System
- Turbine Generator System
- Cooling Water Auxiliary Systems
- Water Treatment Plant
- Compressed Air System
- Fire Protection System
- Electric Power System
- HVAC System
- Vacuum Vessel Pressure Suppression System
- Other Auxiliary and Anxilary Systems

Heat Sources

- Present Power Plants:
  - Single heat source (boiler, fission core)
- Fusion Power Plants
  - Blanket and first wall
  - Divertor
  - Low temperature shield

BoP Systems with Specific Characteristics Relevant to a Tokamak Fusion Power Plant

- Primary Heat Transfer System
- Electric Power System
- HVAC System
- Vacuum Vessel Pressure Suppression System

Requirements for the BoP

- Low contribution to the construction costs (standard components, minimum number of safety relevant systems)

- High reliability and availability

- Scheduled downtimes to be included in the tokamak scheduled downtimes

Topics for Scheduled Maintenance

Frequency depends on:

- Systems architecture (existence and number of redundancies)
- Lifetime of most significant equipment or components

Maintenance duration mainly depends on:

- Scheduling of activities
- Design of most significant equipment
- Accessibility

Topics for Unscheduled Maintenance

Frequency depend on:

- Systems architecture (existence and number of redundancies)
- Components reliability
- Human factor (training, procedures)

Unscheduled maintenance duration mainly depends on:

- Design and accessibility of the less reliable components
- Testability
- Spare parts policy

PPCS Targets

- Plant availability > 80%
- Unscheduled availability < 7%
- Two years full power operation
- Four months shutdown

Availability and Reliability

	Gas Power	Coal Power	Fission Power	Fusion Power	Renew. Power	Solar Power	Hydro Power	Wind Power
Availability (1)	95.0	92.0	92.0	80.0	60.0	22.0	85.0	45.0
Reliability % (2)	92.0	90.0	90.0	88.0	94.0	95.0	95.0	92.0
Serviciability % (3)	87.0	83.0	83.0	66.0	56.0	21.0	81.0	41.0
Process efficiency (4)	0.60 (1)	0.50 (1)	0.36	0.40	0.52	0.2	0.92	0.85

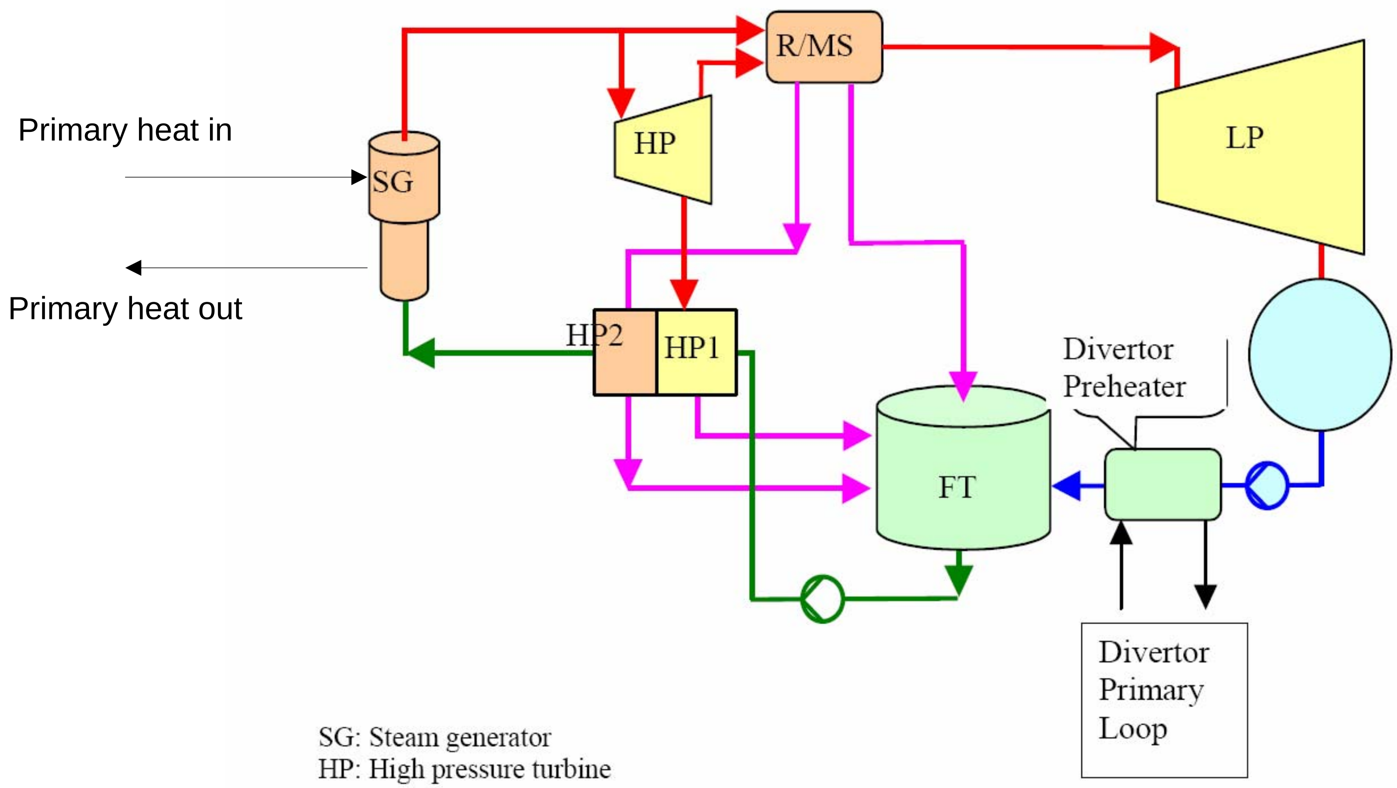
Notes

1. Estimated figures. Availability: here only the planned maintenance is accounted for.
2. The reliability accounts for non planned outages. It has been taken smaller for the more complicated systems. The quoted figures are indicative and open to interpretation; however, if they should change by ± 3% the basic results would not be significantly impacted.
3. The serviciability is the product of (1) x (2).
4. The process efficiency is the thermomechanical efficiency for thermal plants and the hydraulic efficiency for hydro plants.

Comparison of PPCS Reactor Models

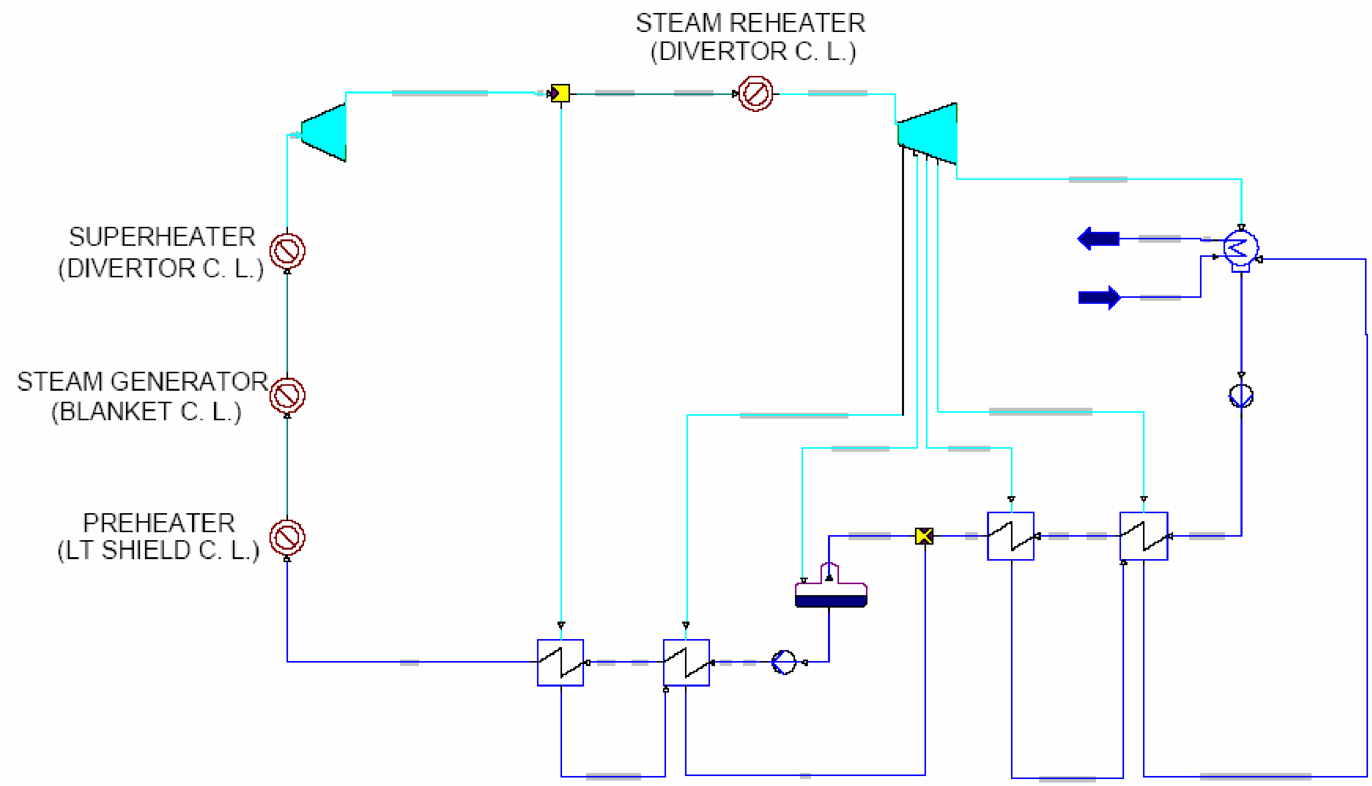
	Model A	Model B	Model C	Model D
Breeder Material	Pb – 17 Li	Li_4 Si 0_4	Pb – 17 Li	Pb – 17 Li
Coolant	Water	Helium	Helium	Pb – 17 Li
Thermal (Fusion) Power (MW_{th})	5,000	3,600	3,400	2,500
Electric Power Output (MWe)	1,500	1,500	1,500	1,500
Efficiency (%)	31	36	41	60
Recirculating Power Fraction	0.28	0.27	0.13	0.11

Power Conversion System Model A

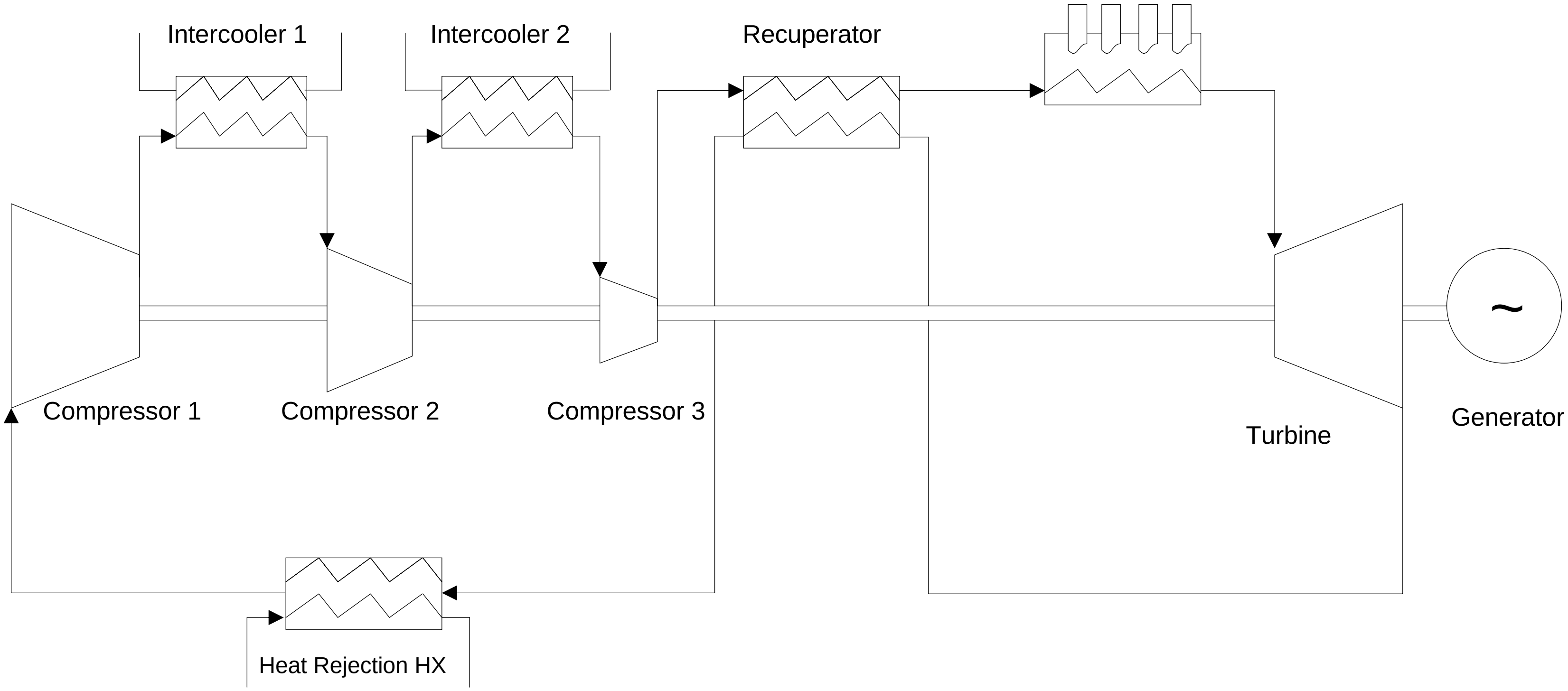


SG: Steam generator
HP: High pressure turbine
LP: Low pressure turbine
HP1, HP2: High pressure heater
R/MS: Reheater/moisture separator
FT: Feedwater tank

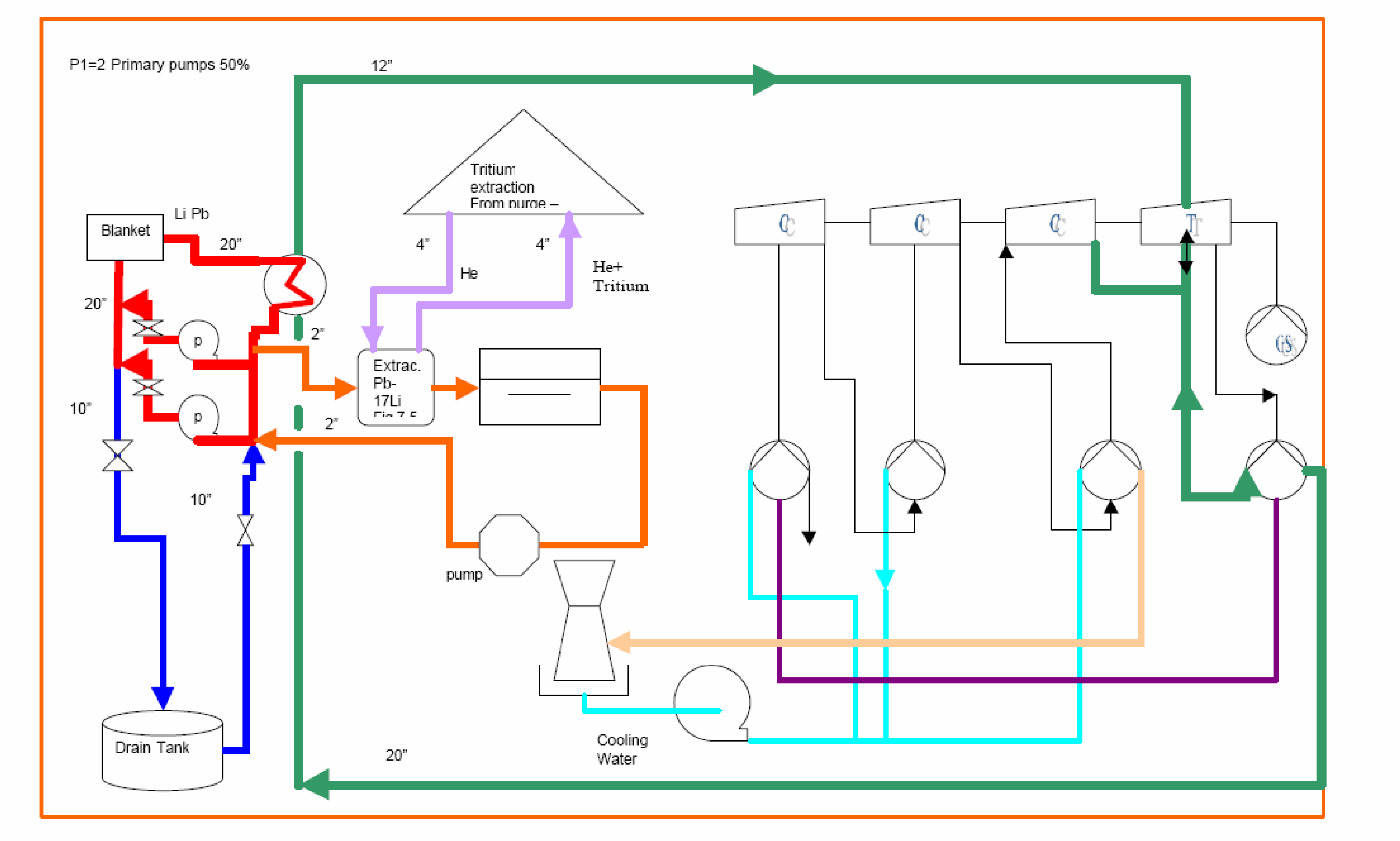
Power Conversion System Model B



Heat Transfer System Model C



Heat Transfer System Model D



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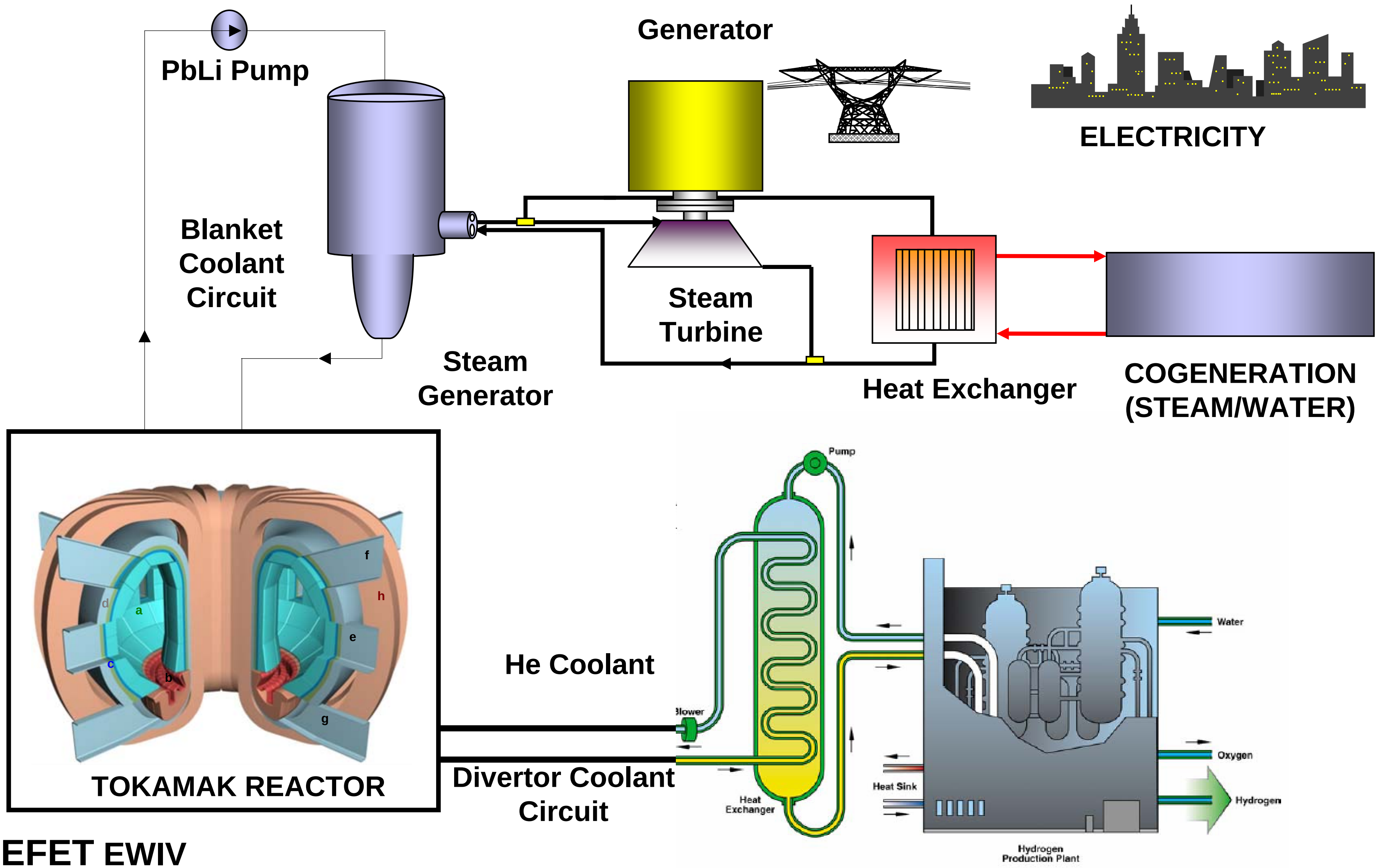
Example of Hydrogen/electricity Production Scheme



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Similar PPCS technologies to Generation IV Fission Reactors

- **Gas Cooled Fast Reactor system - relevant synergies with Model B**

  He coolant, He loops and Turbomachinery technologies (490ºC-850ºC He temperature ranges)

- **Very high - Temperature Reactor - relevant synergies with Model B and Model C**

  High temperature, He loops and heat exchangers (1000ºC) for thermochemical H_2 production.

- **Supercritical - Water Cooled Reactor - Model A**

  Model A may be further optimised for high pressure water cooled blankets and divertor operating above thermodynamic critical point of water (374ºC, 22.1 MPa).

- **Lead Cooled Fast Reactor - Model C**

  Material technology, heat transport, energy conversion and chemistry for lead (PbLi/PbBi) coolant systems.

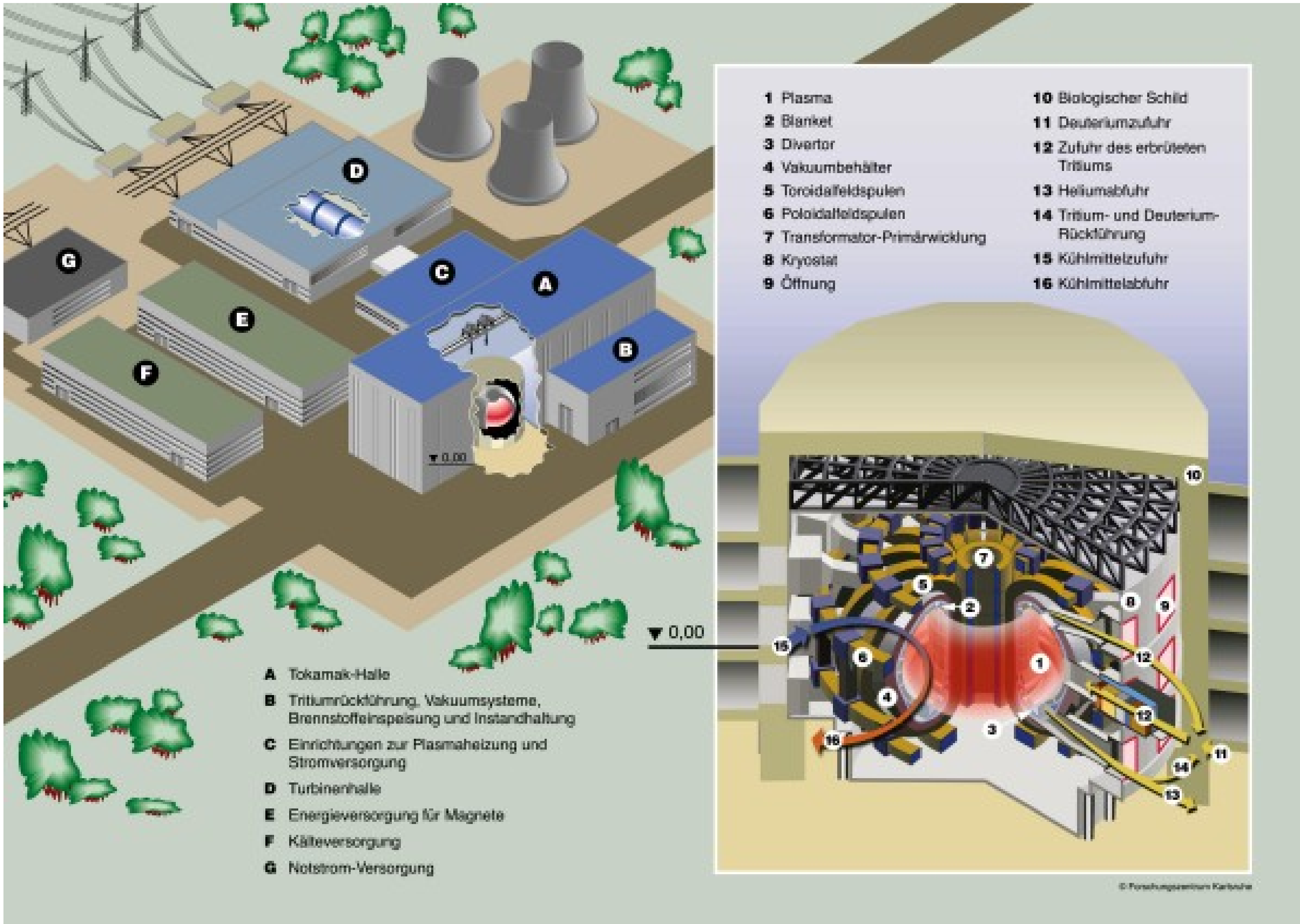
Conclusions

- BoP systems play an important role for the reliable operation of a Fusion Power Plant.
- Heat transfer system and power supply have to meet specific characteristics of fusion power.
- The availability of the BoP has to compensate for the comparable low availability of the tokamak due to specific maintenance requirements.
- High efficient plant designs have been described in the PPCS but require future technologies still to be developed.

Conclusions cont.

- The availability factor is considered a key parameter in the Fusion Power Plant feasibility demonstration.
- Experience in Fission Plants shows that BoP availability is an important contribution to this parameter.

The Future



Source: FzK

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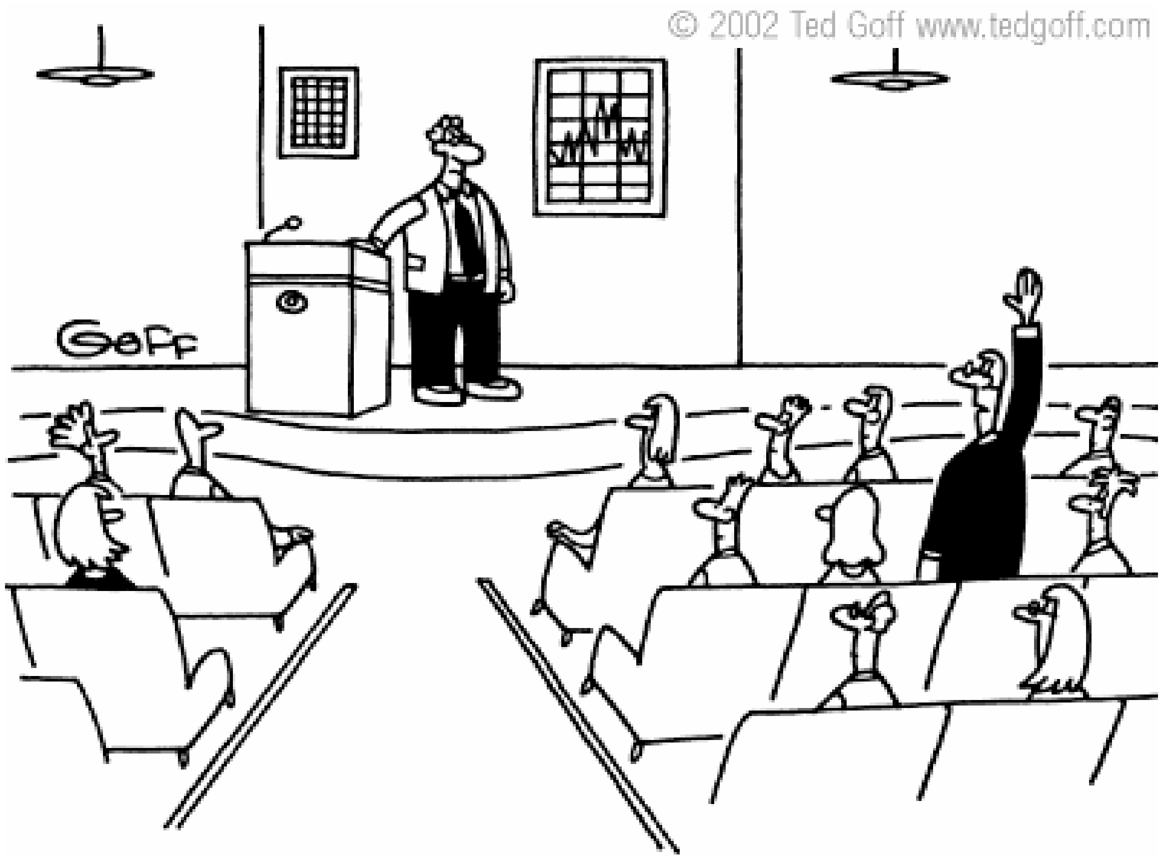
Any questions? Please go ahead!



"Did you just say that anyone who asks another question will be fired?"