POLITECNICO DI TORINO

Development of a system-level thermal-hydraulic model for tokamak fusion reactors

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EUROfusion

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POLITECNICO DI TORINO

Who I am

- BSc in Mechanical Engineering (Università della Calabria, 2012)
- MSc in Energy and Nuclear Engineering (Politecnico di Torino and Politecnico di Milano, double degree, 2014)
- PhD in Energetics (Politecnico di Torino, 2018)

- EUROfusion Engineering Grant in Work Package BoP 2018-2021
- Assistant professor at Politecnico di Torino since July 2018

- Research topic: modelling for Breeding Blanket and BoP of tokamak fusion reactors

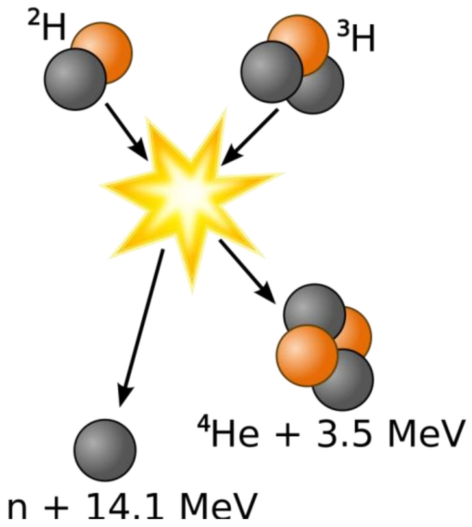
Outline

- Introduction
- The EU DEMO Breeding Blanket and Primary Heat Transfer System
- Multiscale modelling approach
- The GETTHEM code
- Conclusions & perspective

Fusion energy

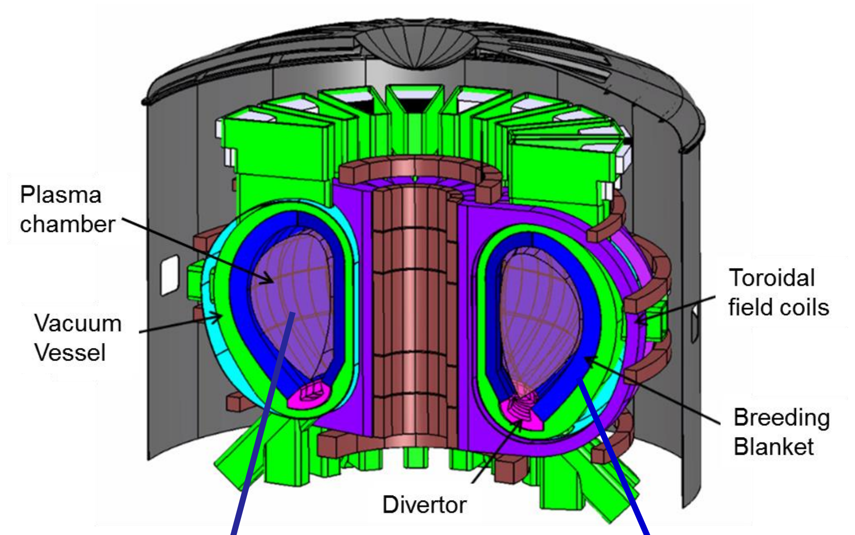
Fusion is universally considered to be an important *clean* energy source for the future:

- Advantages wrt other energy sources (common with fission)
  - Can cover baseline load (renewables cannot!)
  - No CO_2 emissions (conversely to fossil)
- Advantages wrt nuclear fission
  - No chain reactions ("automatic" shutdown in case of accidents)
  - Smaller amount of radioactive materials
  - Large availability of fuels



EU DEMO

- EU DEMO aims to prove economic feasibility of fusion electricity
  - First reactor to include Power Conversion System and to breed tritium in situ → Breeding Blanket (BB)
- BB is the first component facing the plasma → largest total thermal load from plasma + nuclear reactions



[1]

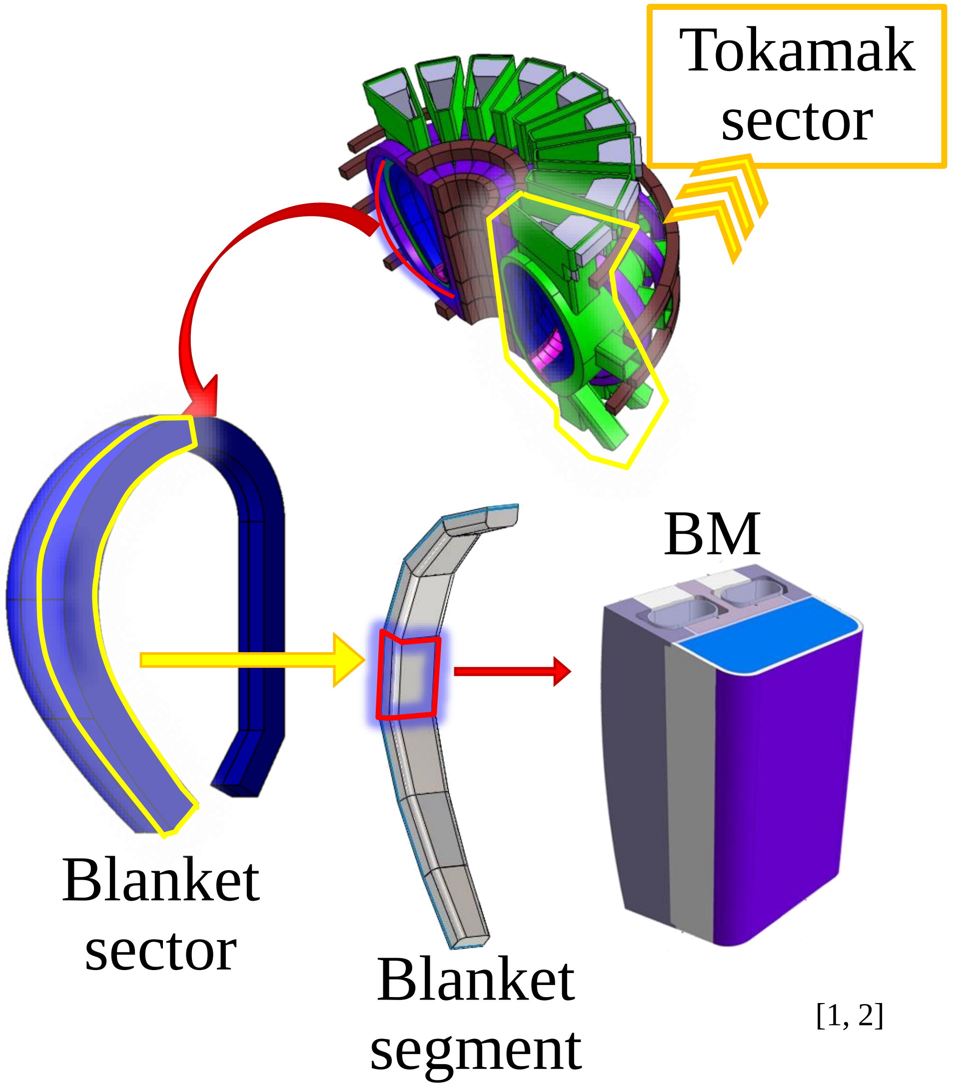
D(T,n)He + 17.6 MeV

^{6}Li(n,α)T + 4.8 MeV

^{7}Li(n,n′α)T – 2.5 MeV

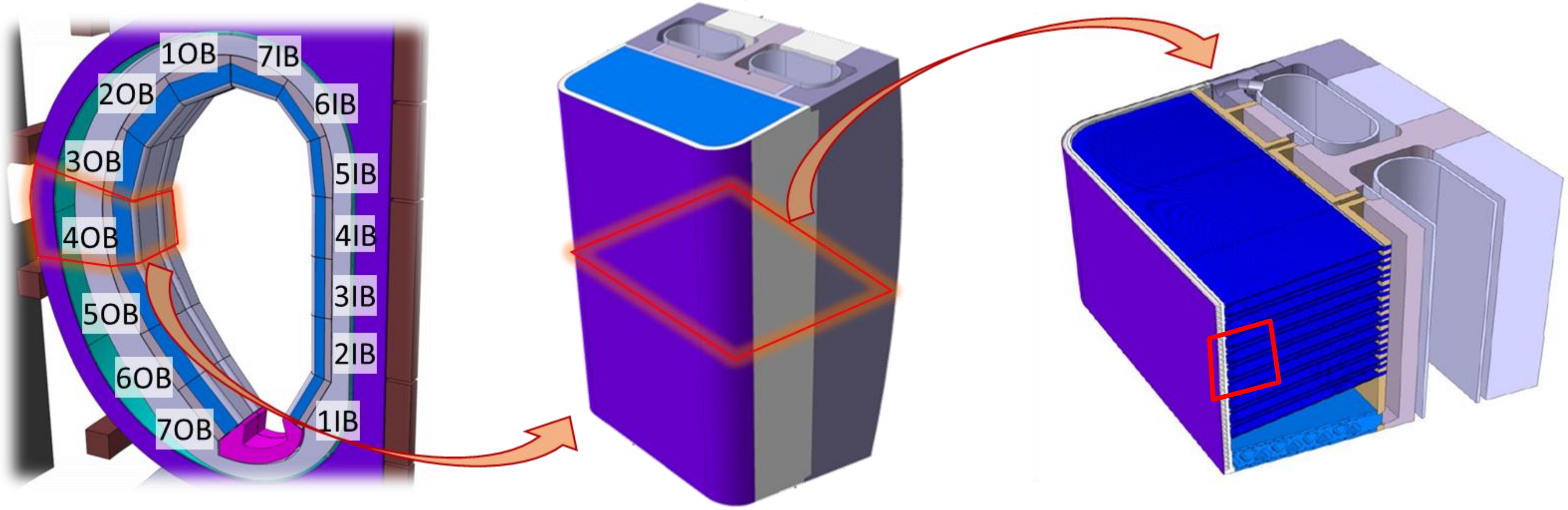
The EU DEMO BB

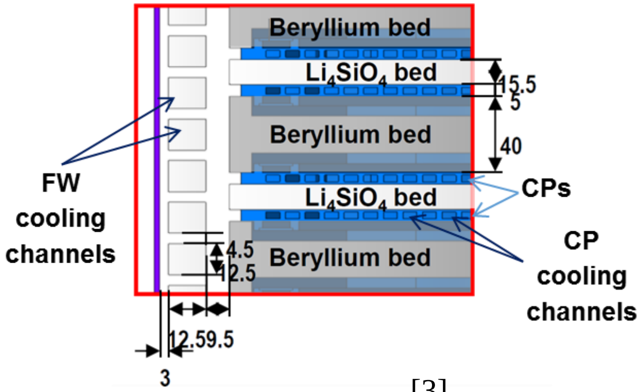
- Tokamak toroidally divided in sectors
- Each sector → 2 inboard (IB) and 3 outboard (OB) BB segments
- Each segment → several Blanket Modules (BMs)
- First Wall (FW) and Breeding Zone (BZ)
- 4 BB concepts:
  - Helium-Cooled Pebble Bed (HCPB)
  - Water-Cooled Lithium-Lead (WCLL)
  - Helium-Cooled Lithium-Lead
  - Dual Cooled Lithium-Lead



[1, 2]

HCPB



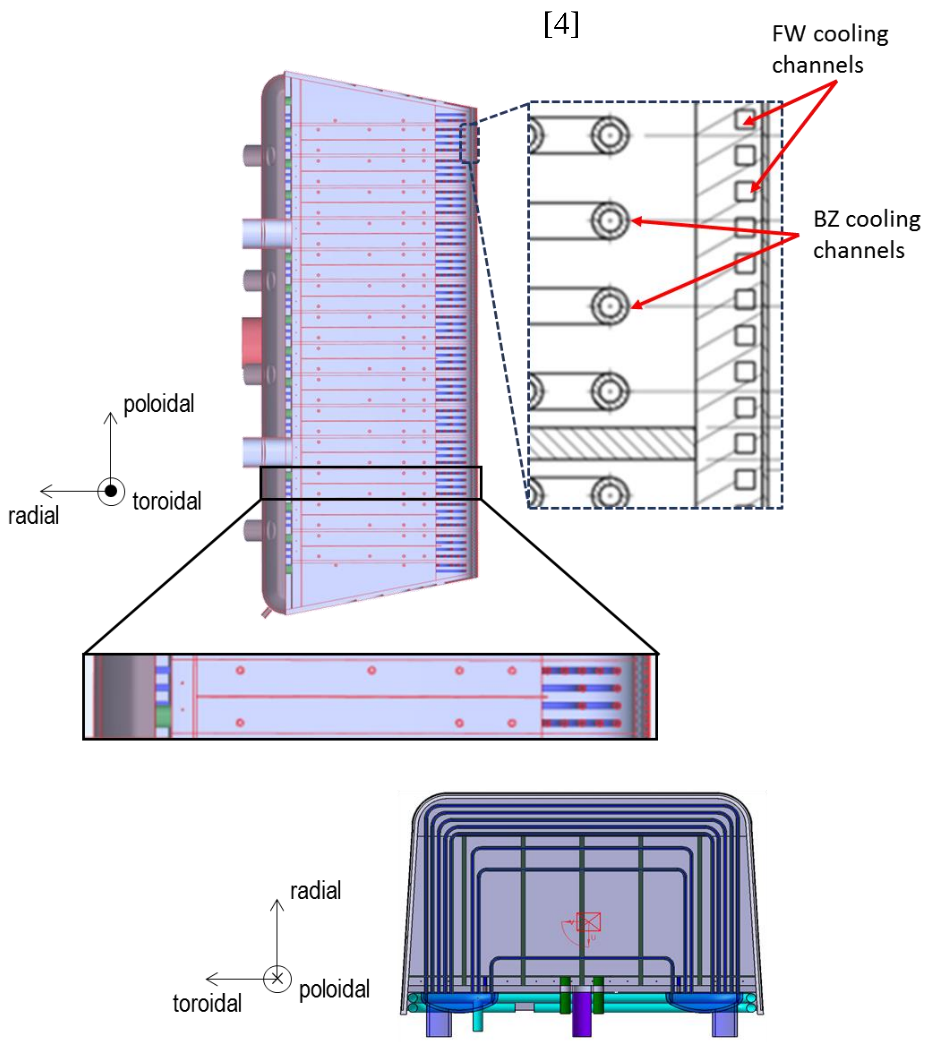


[3]

- Coolant: He (8 MPa, 300 – 500 ˚C)
- Breeding material: Li_4SiO_4 pebbles
- *n* multiplier: Be pebbles
- FW and BZ cooled in series (~2000 cooling channels per BM)
  - Square FW cooling channels
  - Rectangular BZ cooling channels, inside metallic Cooling Plates (CPs)

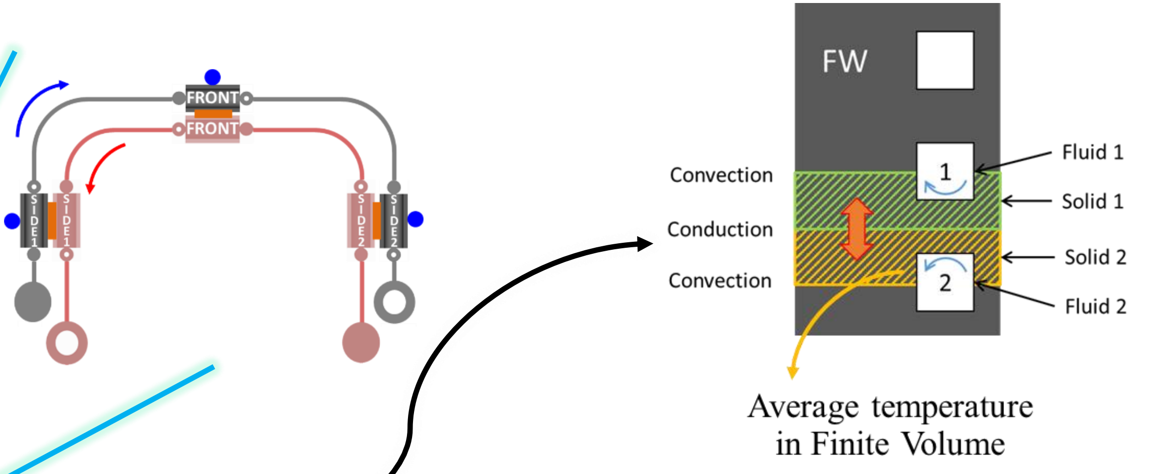
WCLL

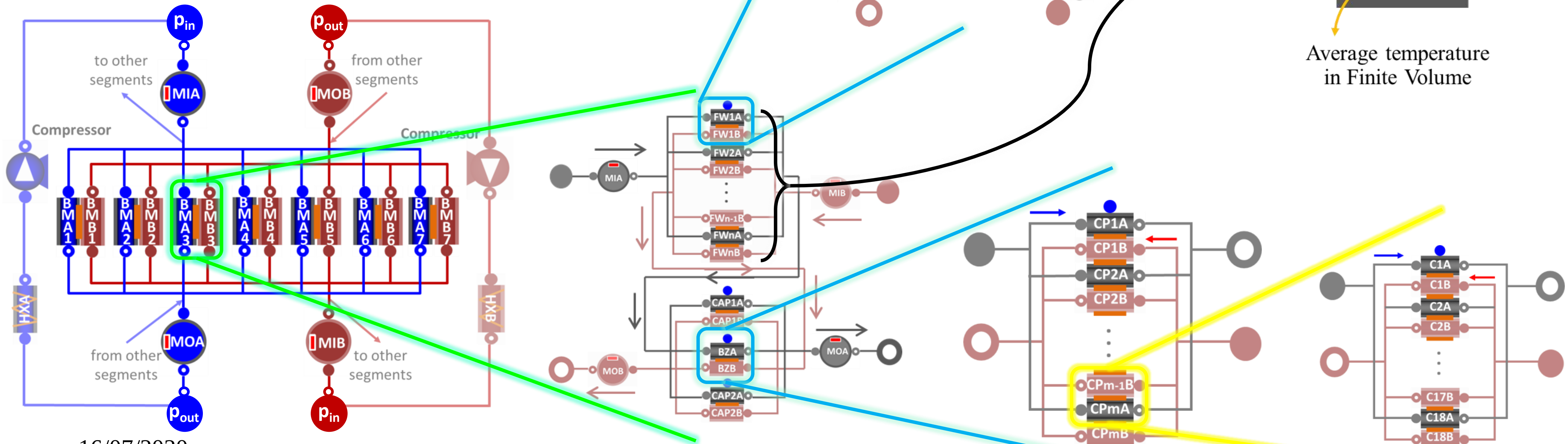
- Coolant: Water (15.5 MPa, 285 – 328 °C)
- Breeding & *n* multiplier material: PbLi eutectic (liquid)
- FW and BZ cooled by different loops (~500 cooling channels per BM)
  - Square FW cooling channels
  - Circular BZ cooling channels



Multiscale modelling approach

- Full circuit model is broken down to the microscale
- At microscale → solution of 1D mass, momentum and energy conservation in fluid + 1D energy conservation in solid (lumped parameter)
- Relevant information (e.g. peak temperature) is propagated to the upper scales





[5, 6]

The GETTHEM code

GEneral Tokamak THErmal-hydraulic Model

- Main features:
  - Lumped-parameter, system-level code developed using the equation-based, object-oriented Modelica language → user-friendly
  - Allows fast simulation of thermal-hydraulic transients in the entire PHTS
- Development started in 2015
  - Verification against simple tests
  - Benchmark:
    - Against 3D CFD in 2016 (WCLL) [7] and 2017 (HCPB) [6] for nominal operation
    - Against CONSEN in 2016 for HCPB LOCA [8]
    - Against RELAP and MELCOR ongoing for LOCA
  - Validation against experiments in 2016 for WCLL LOCA [9]
- Different applications in nominal and accidental transients [6, 7, 9-12]

GETTHEM features and future improvements

- Fast-running tool for thermal-hydraulic simulation of BB and PHTS:
  - ✓ Use water and helium as working fluids
  - ✓ Applicable in nominal conditions and accidental transients
  - ✓ Can be used for parametric studies → provide hints to design team, to rapidly identify strong and weak points of the design
  - ✓ System-level code, still keeping good level of detail at lower scales

- Modular approach → easy extension:
  - →Module for magnetohydrodynamics under implementation → PbLi flow inside the magnetic field [to be presented at ANS TOFE 2020]
  - →Activated Corrosion Product transport model under implementation → safety analyses
  - →Potential for further extensions, e.g. Plant Electrical Systems model, with minimum development cost

Conclusions & perspective

The (thermal-hydraulic) modelling of a tokamak requires modelling several space- and time-scales

- A new code has been developed to tackle this problem
- Its predictions have been qualified against other codes or experiments
- A modular approach has been used to ensure simple development of new features
- Long-term aim is to build a comprehensive tool, able to model all the processes involved in the power extraction, as well as a code to support safety analyses

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