A **V**irtual **R**eactor **M**odel for **I**nertial **F**usion **E**nergy

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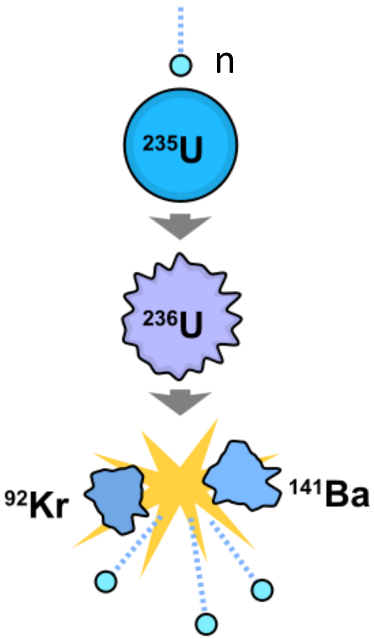
OUTLINE

- Introduction
  - Fusion vs Fission
  - Inertial Confinement Fusion Principle
  - Reactor Concept
- Why a Virtual Reactor Model ?
- VXM: definition & theory
- HIPER VRM: Context Elements

Thermonuclear Energy

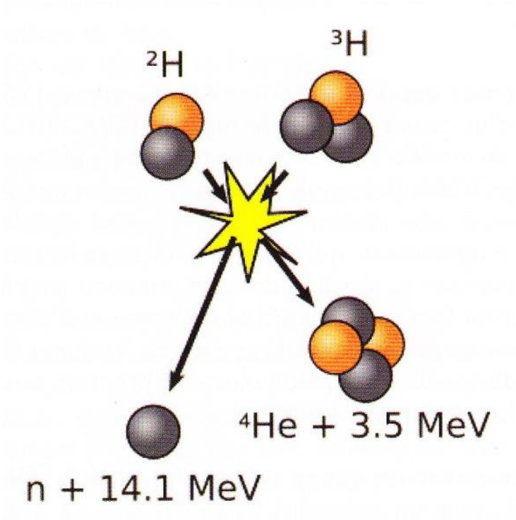
Fission



90 GJ / g

Long life radioactive waste !!

Fusion



340 GJ / g

Thermonuclear Fusion

- Thermonuclear fusion of light elements
  - Easier reaction : D + T → ^{4}He (3,5MeV) + n (14,1MeV)

- Lawson Criterion for a positive energy balance:

$$n_{\text{(particle density)}} \times \tau_{\text{(reaction duration)}} \geq k$$

$$k = 10^{14}\ \text{cm}^{-3} \text{ at } 200\ \text{MK}$$

→ two options :

Thermonuclear Fusion

- **M**agnetic **C**onfinement **F**usion
  - Low density : $n \approx 10^{14}$ cm^{-3}
  - Nearly continuous process

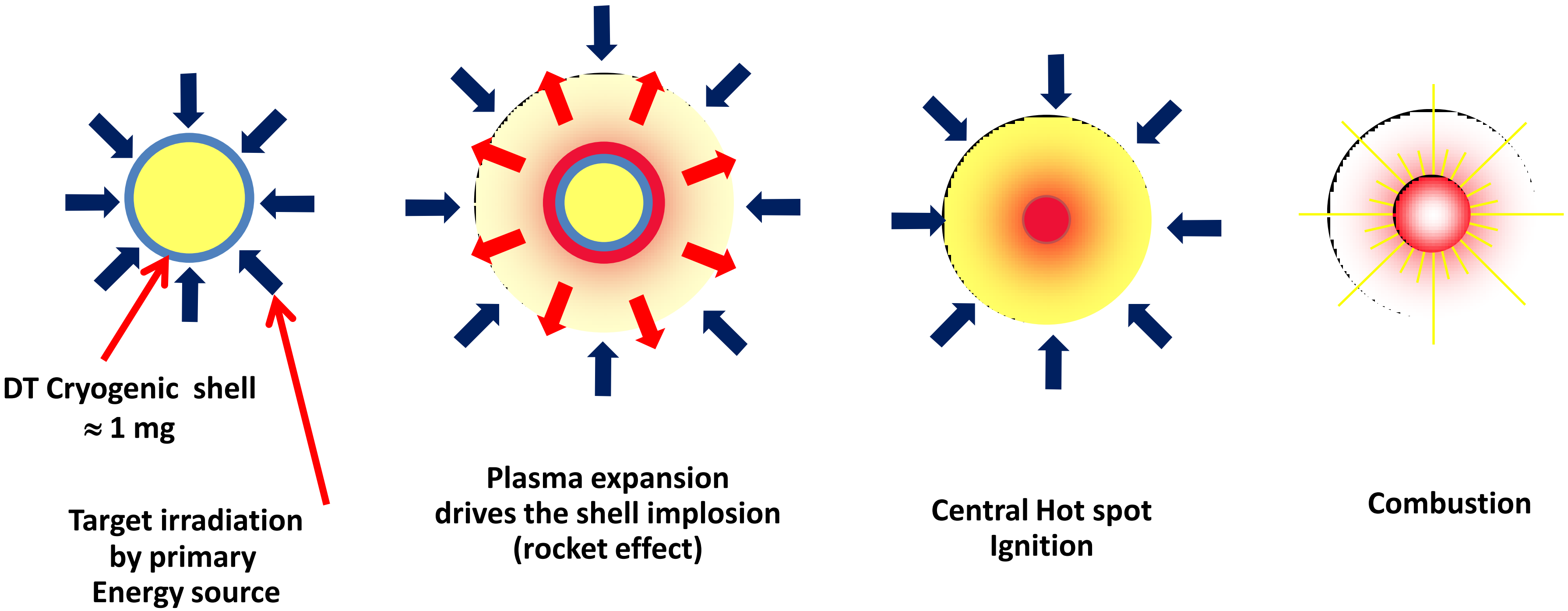
Tokamaks → ITER

- **I**nertial **C**onfinement **F**usion
  - High density : $n \approx 10^{26}$ cm^{-3}
  - Short life time : $\tau \approx$ qq.10^{-11} s
  - Repetition rate ≈ 10 Hz

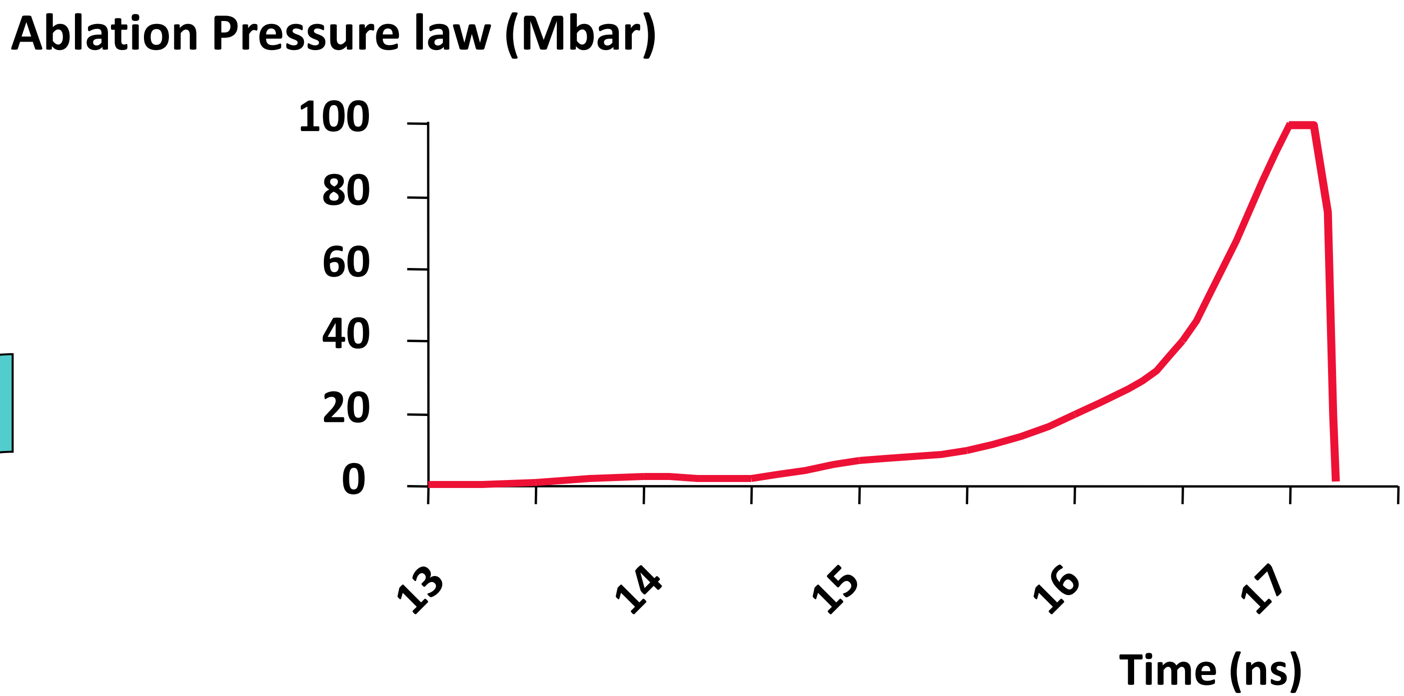
High power pulsed laser → HIPER

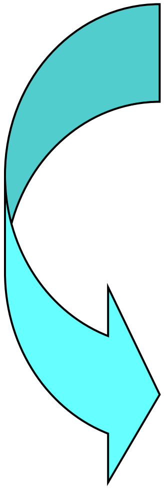
What is Inertial Confinement Fusion ?

ICF principle



Primary energy source for ICF





Primary Energy source

Intensity : 2.10^{13} - 2.10^{15} W/cm^2

Energy : 1 - 10 MJ.

Duration : ~ 10 ns

Energy source for ICF

- Only high power pulsed lasers can provide (today) the required performance.
  - Laser-matter interaction and implosion experiments have been widely studied since the sixteen's

- Two large laser facilities are expected to demonstrate ICF (with a small thermonuclear gain) in the current decade: LMJ in France and NIF in USA.

ICF demonstration

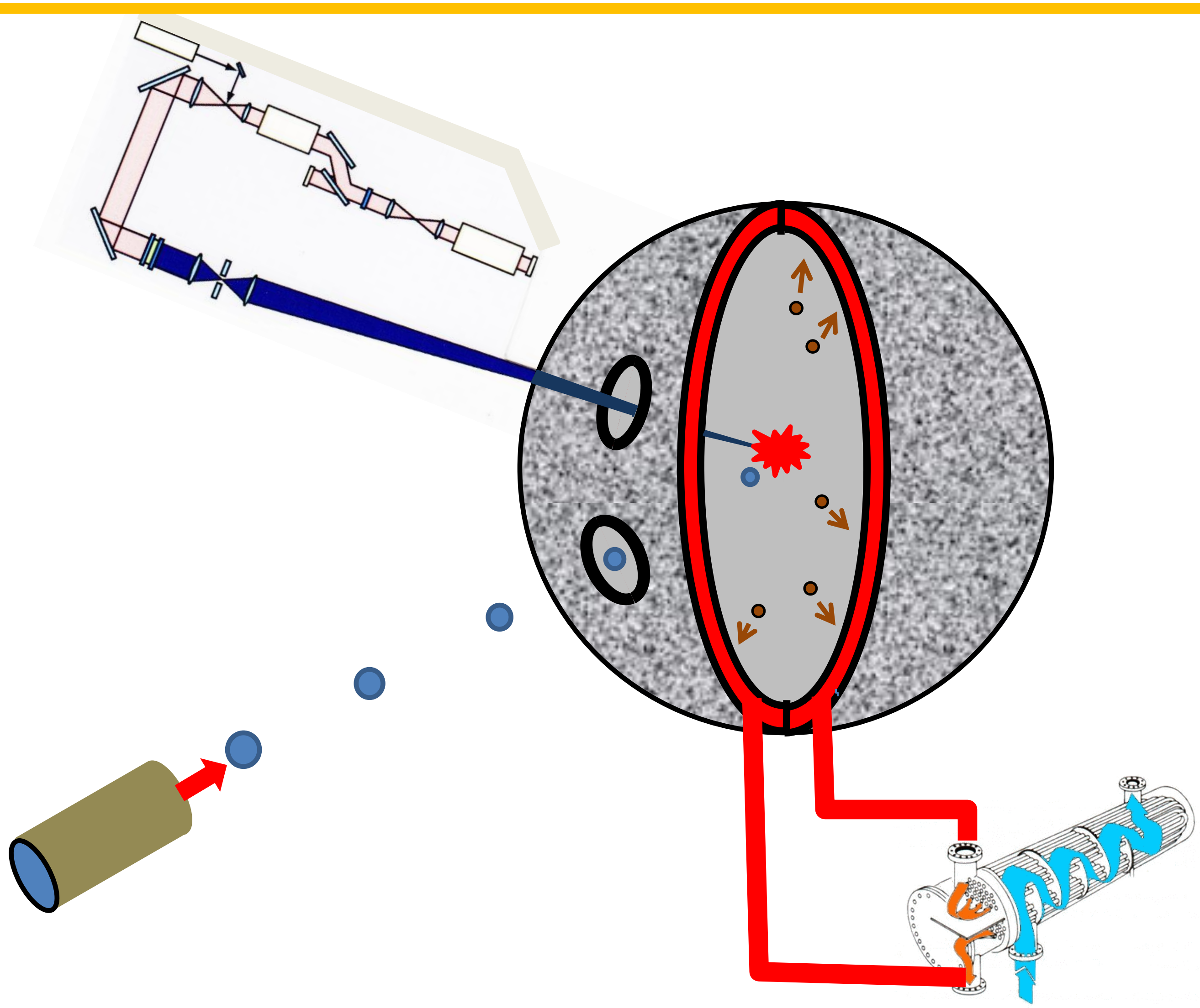
Laser Megajoule (LMJ - PETAL)
Bordeaux - CESTA

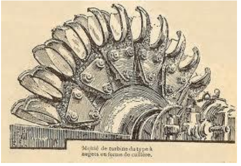
National Ignition Facility (NIF)
Livermore - LLNL

Next step : HIPER
a reactor for **I**nertial **F**usion **E**nergy

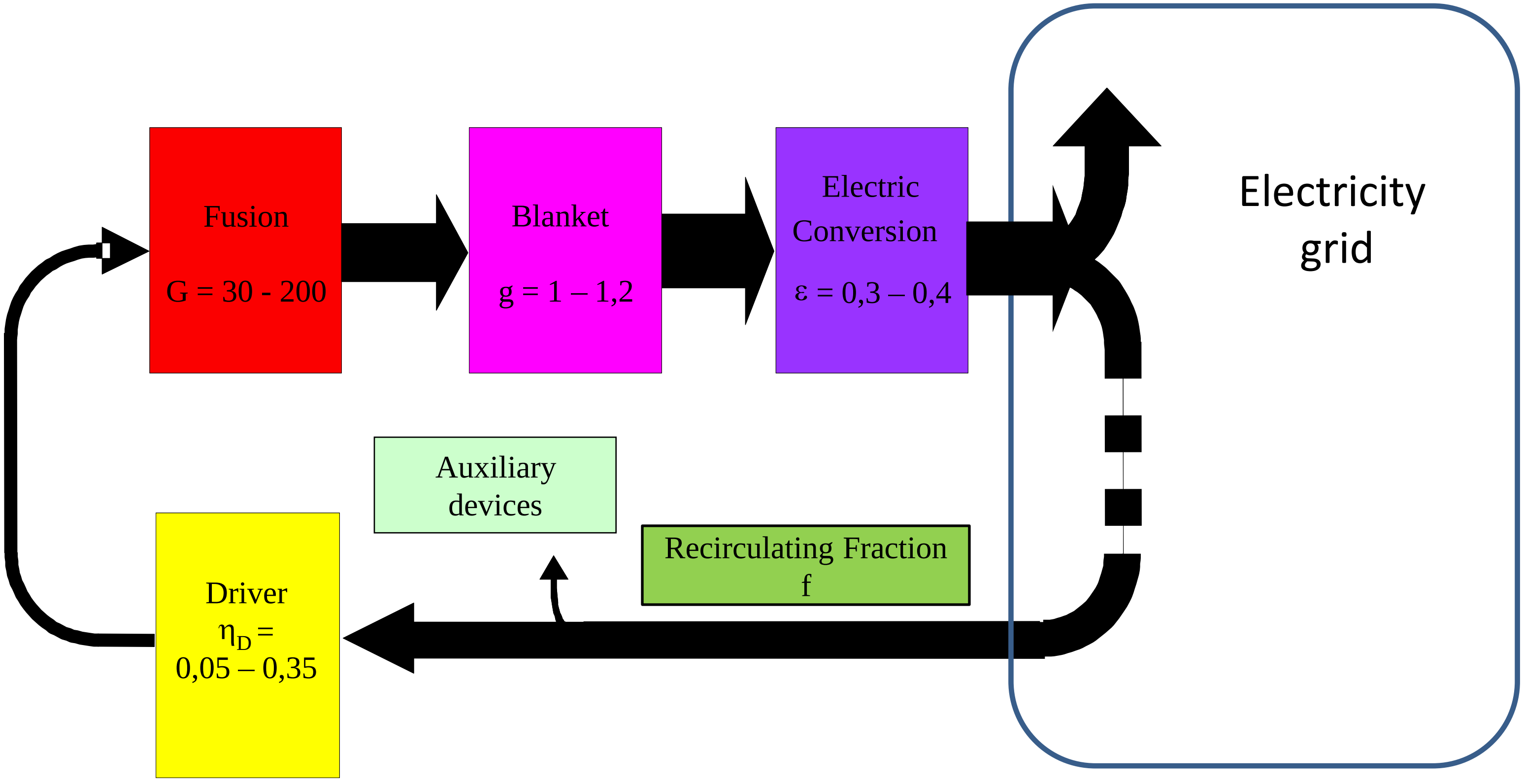
- HIPER will be the European **HI**gh **P**ower Laser **E**nergy **R**esearch facility
- Objectives :
  - "single build" demonstration power plant
  - Minimum infrastructure required to achieve fusion at a level capable of a significant energy surplus
  - Time required to plan, fund, design, construct and commission a pilot plant of this scale estimated at 20 – 30 years

Elements of an IFE Reactor



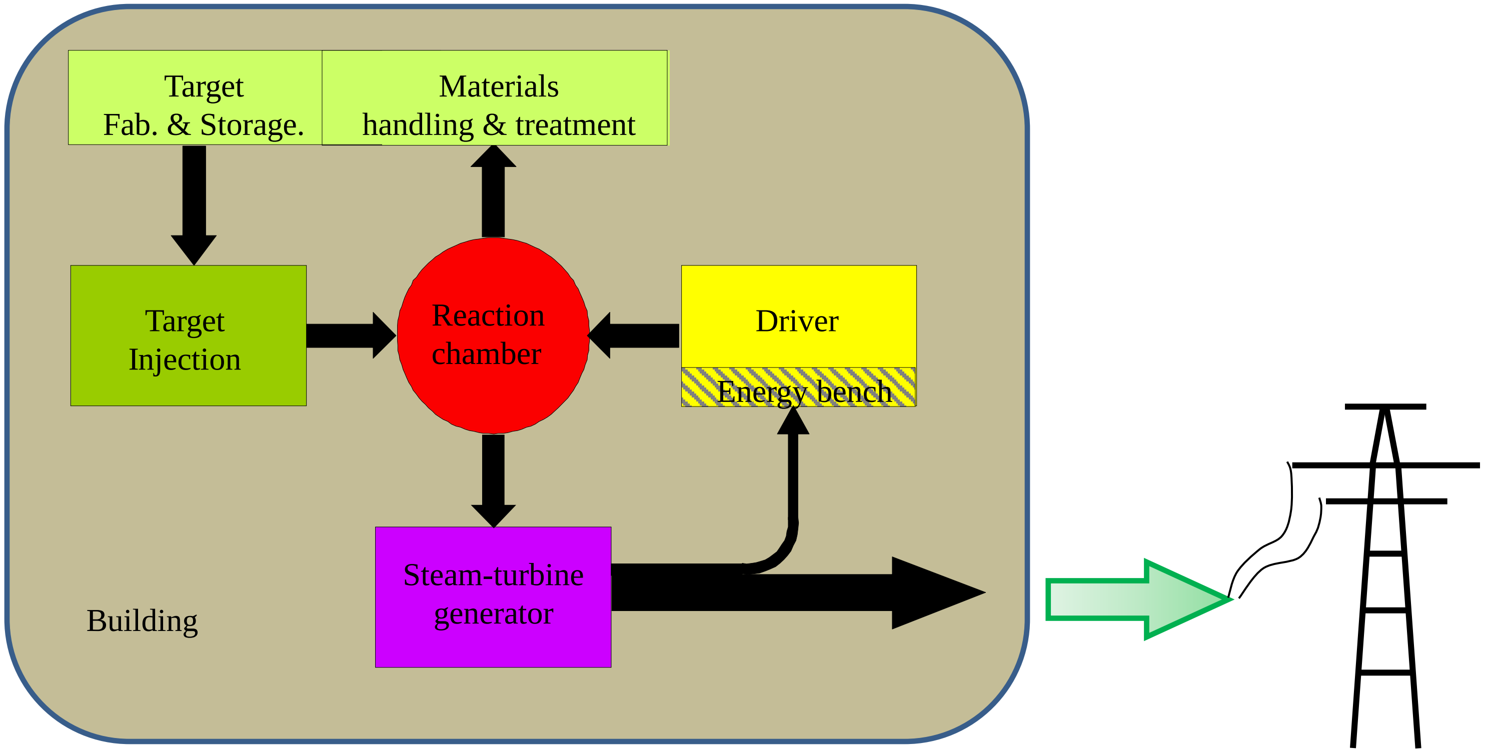


Energy loop of an IFE reactor

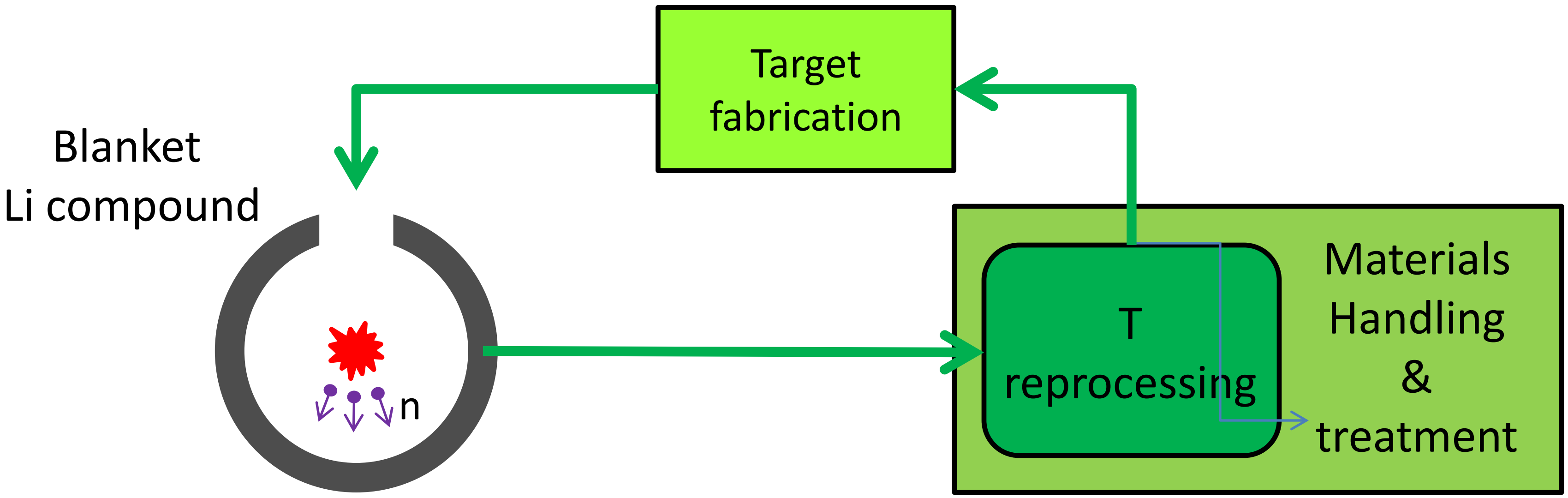


Repetition rate ~ 10 Hz for 1 GW yield

IFE Reactor structure



Tritium loop in an IFE reactor

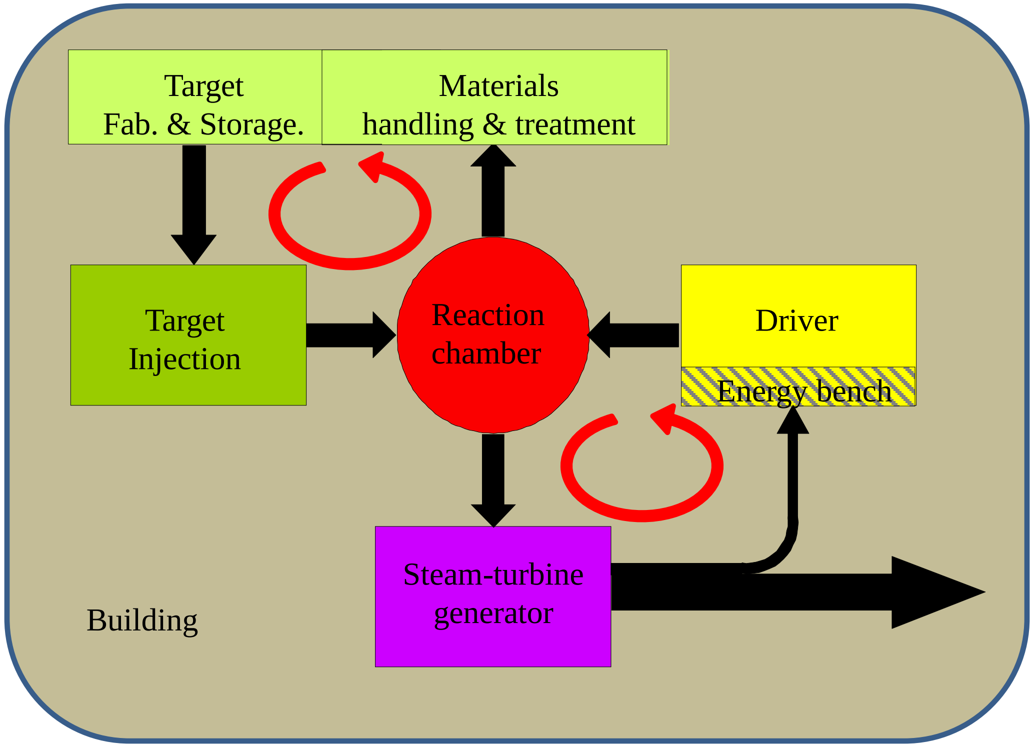


$$\begin{cases} {}^{6}Li + n \rightarrow T + {}^{4}He + 4{,}8\ MeV \\ {}^{7}Li + n + 2{,}5\ MeV \rightarrow T + {}^{4}He + n' \end{cases}$$

T breeding ratio ~ 1,15

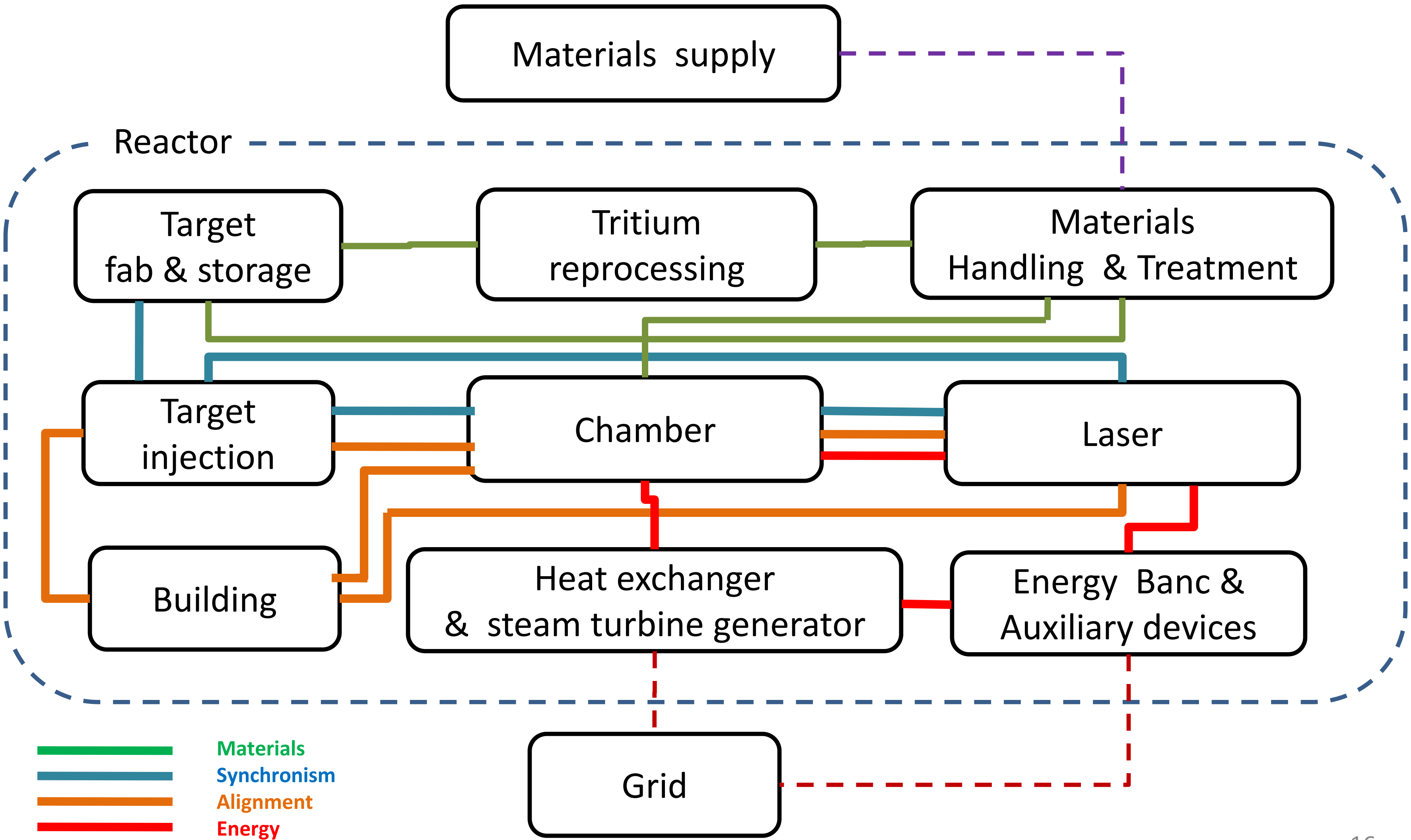
Why a Virtual Reactor Model ?

Two loops are obvious



However…

Why a Virtual Reactor Model ?



Developping a VRM: Why?

- In order to validate VIRTUALLY the concept and to develop the design (R&D)
- To go « one shot » towards the demonstration powerplant (Engineering Development)

Virtual-X: major concepts (theory)

➢Definition

The Virtual-X is a mean to simulate X assembly (physical design) and X operations (functional design) of the "to-be" X before its actual integration in order deliver at TRLX a "competitive", "OK for operations & services", "OK for certification" and "OK for production" definition file

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VXM : the theory

Operational & Functional Analysis

- Identification, organization and characterization of operations and functions
- Production of supporting models (trees, scenarios...)
- Derive "system" requirements

Model Based System Engineering

- Formal modeling of the operations and functions (scenarios, flow ...)
- Formal modeling of the functional and physical architecture
- Derive "technical" requirements
- Modeling of specifications

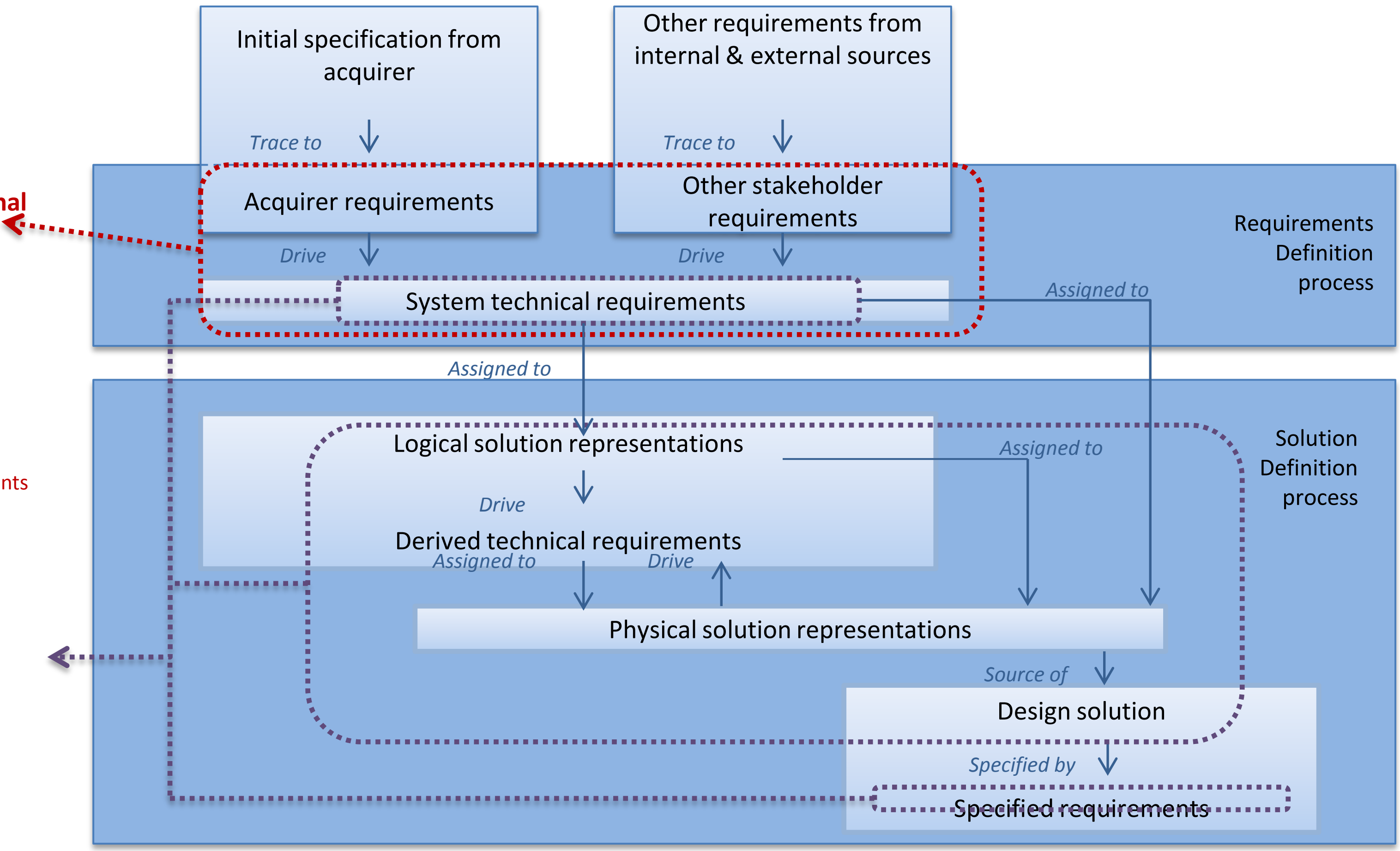

Figure 1 – Mapping of bundle activities on EIA 632 building block design process

HiPER

Virtual-X: major concepts (theory)

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➢Induced Tasks – Identify/Establish:

- Functionnal Architecture
- X End-to-End Numerical Process (workflow analysis with input/output data)
- Virtual Testing Generic process
- Virtual Labs Developments (for each sub-system)
- CCL: CAD-CAE links (tools + management)
- Back-bone unified middleware for managing simulation data, hierarchical models (from analytics to numerical multiscale and multiphysics models) and results (SLM tool)

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HIPER VRM: Some Context Elements (Practice)

➢A « very complex » system

- Major Sub-systems decomposition – Coupling loops identification
- European – Multi-teams Collaborative Project

➢Code Packages :

- Under development for each sub-system with different maturity levels

➢Process :

- Simulation-Based Design Decisions
- Numerical Design associated to experimental programs

➢Constraints/Difficulties :

- Multi-purpose:
  - Simulation-Based Global Performance Demonstration
  - Used for virtual tests (scientific tool)
  - Fexibility towards scientific codes developments and improvments
  - V&V and robustness

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HIPER VRM in practice

- Exhaustive Functional Analysis
- Set of nominal processes and critical events to be simulated
- Examples of processes to be simulated:
  - Ignition/Combustion Process
  - Target Engagement
  - Neutron energy deposition and Heat Exchange