REVOLVER-D: The Ergodic Limiter/Divertor Consisting of Molten Tin Shower Jets Stabilized by Chains

J. Miyazawa[1,2], T. Goto[1,2], T. Ohgo[2], N. Yanagi[1,2], T. Murase[1], H. Tamura[1], H. Tanaka[3], T. Tanaka[1,2], R. Sakamoto[1], S. Masuzaki[1], A. Sagara[1,2], and the FFHR Design Group

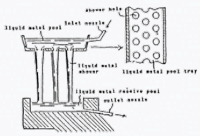
[1]National Institute for Fusion Science, 322-6 Oroshi-cho, Toki, Gifu 509-5292, Japan
[2]SOKENDAI (The Graduate University for Advanced Studies) , 322-6 Oroshi-cho, Toki, Gifu 509-5292, Japan
[3]Nagoya University, Furo-cho, Chikusa-ku, Aichi 464-8603, Japan

1. Introduction

- The conceptual design of the **FFHR-d1** (LHD x 4) is ongoing
- The peak divertor heat load will exceed **20 MW/m²** (max. for the ITER divertor)
- Sustainment of detachment with poor measurement and actuator will be quite difficult
- A new liquid metal ergodic limiter/divertor concept named the **REVOLVER-D** (Reactor-oriented Effectively VOLumetric VERtical Divertor) is proposed

2. Shower of Molten Tin Sheath Jets as the Plasma Facing Component

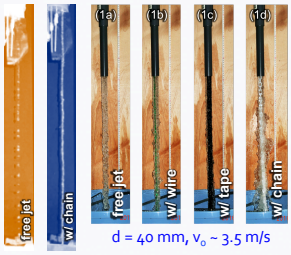
- The liquid metal shower concept was already proposed 30 years ago
- In the case of FFHR-d1, the falling distance is ~4 m
- Acceleration by the gravity is not necessarily favorable: narrowing jet diameter, unstable jet surface, splashing at the pool, droplet formation



K. Maki, IAEA-TECDOC-373 (1986) 87

Formation of the "Sheath Jet"

- An internal flow resistance of wire/tape/chain is inserted to the jet ➔"Sheath Jet"
- To decelerate and stabilize the jet
- On the other hand, the turbulence inside the jet will be enhanced

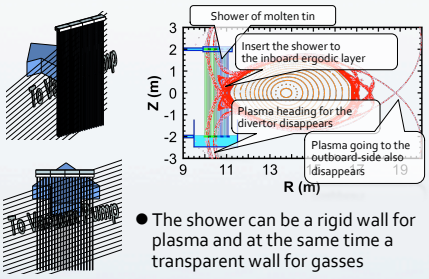


d = 7 mm, v_0 ~ 2 m/s

d = 40 mm, v_0 ~ 3.5 m/s

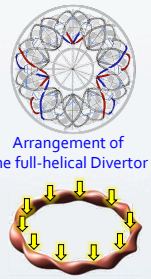
Water Jets with or w/o internal flow resistance

The Shower is Used as the "Ergodic Limiter/Divertor"



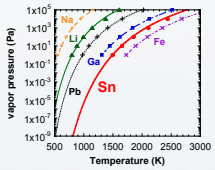
- The shower can be a rigid wall for plasma and at the same time a transparent wall for gasses

Easy Maintenance is Crucial for the Fusion Reactor

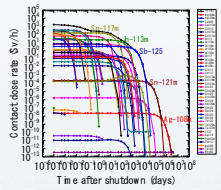


- The full-helical divertor as in the LHD is complicated
- Maintenance is quite difficult
- The showers of the REVOLVER-D is localized at 10 inner ports
- Easy maintenance by simple up/down motions is possible

Molten Tin is the Best Candidate for the Liquid Metal Divertor



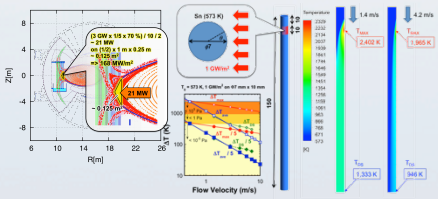
Vapor pressures of various metals of low melting point



Contact dose rate of tin after 30 days of 3 GW DT fusion operation in the FFHR-d1 (EASY-2005)

- Tin has various merits of low melting point, low vapor pressure, low cost, low toxicity, no reaction with water, and high nuclear stability

The Heat Load on the Ergodic Limiter/ Divertor is Extremely High, But Tolerable

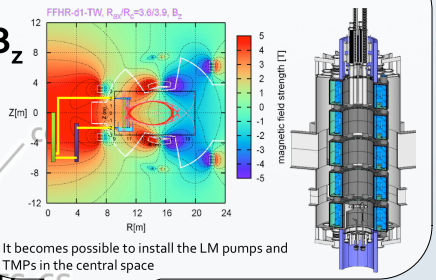


- The heat load is ~170 MW/m² at 3 GW of fusion output
- ΔT of tin can be kept at ~200 K even in this case, if each of the 10 showers are operated with 800 kg/s of flow rate

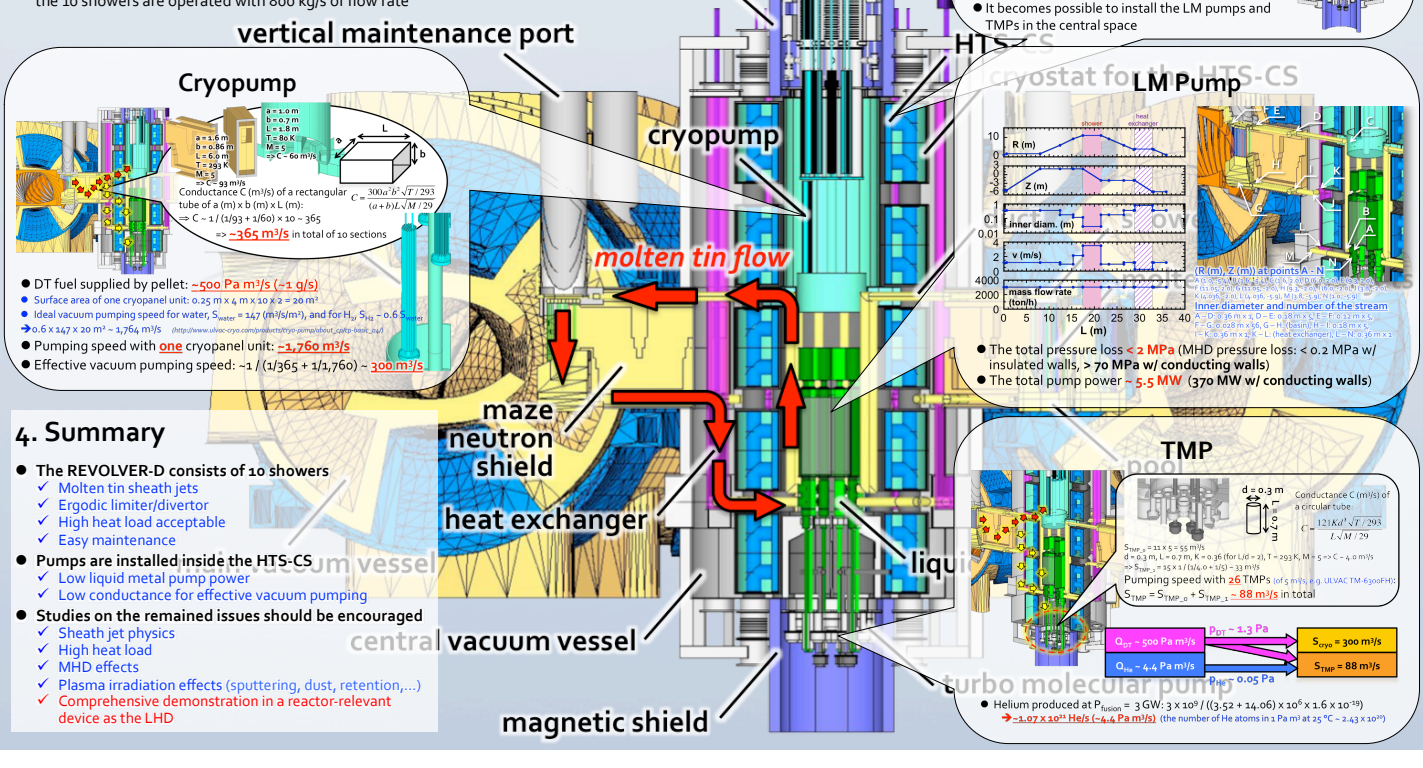
3. The REVOLVER-D System

- 10 major components:
  - ✓ Liquid Metal (LM) Pump
  - ✓ Ducts
  - ✓ Showerhead
  - ✓ Pool
  - ✓ Heat Exchanger
  - ✓ High-Temperature Superconductor Central Solenoids (HTS-CS)
  - ✓ Central Vacuum Vessel
  - ✓ Maze Neutron Shield
  - ✓ Cryopump Unit
  - ✓ Turbo Molecular Pump (TMP) Unit

HTS-CS



- It becomes possible to install the LM pumps and TMPs in the central space



Cryopump

- DT fuel supplied by pellet: ~500 Pa m³/s (~1 g/s)
- Surface area of one cryopanel unit: 0.25 m x 4 m x 10 x 2 = 20 m²
- Ideal vacuum pumping speed for water, S_{water} = 147 (m³/s/m²), and for H_2, S_{H_2} ~ 0.6 S_{water}
  ➔0.6 x 147 x 20 m² ~ 1,764 m³/s (http://www.ulvac-cryo.com/products/cryo-pump/about_cryo-basic_pu/)
- Pumping speed with one cryopanel unit: ~1,760 m³/s
- Effective vacuum pumping speed: ~1 / (1/365 + 1/1,760) ~ 300 m³/s

LM Pump

- The total pressure loss < 2 MPa (MHD pressure loss: < 0.2 MPa w/ insulated walls, > 70 MPa w/ conducting walls)
- The total pump power ~ 5.5 MW (370 MW w/ conducting walls)

TMP

- Helium produced at P_{fusion} = 3 GW: 3 x 10⁹ / ((3.52 + 14.06) x 10⁶ x 1.6 x 10⁻¹⁹)
  ➔~1.07 x 10²¹ He/s (~4.4 Pa m³/s) (the number of He atoms in 1 Pa m³ at 25 °C ~ 2.43 x 10²⁰)

4. Summary

- **The REVOLVER-D consists of 10 showers**
  - ✓ Molten tin sheath jets
  - ✓ Ergodic limiter/divertor
  - ✓ High heat load acceptable
  - ✓ Easy maintenance
- **Pumps are installed inside the HTS-CS**
  - ✓ Low liquid metal pump power
  - ✓ Low conductance for effective vacuum pumping
- **Studies on the remained issues should be encouraged**
  - ✓ Sheath jet physics
  - ✓ High heat load
  - ✓ MHD effects
  - ✓ Plasma irradiation effects (sputtering, dust, retention,...)
  - ✓ Comprehensive demonstration in a reactor-relevant device as the LHD