Inv. Lecture at Oak Ridge National Laboratory, Oct.25, 2010

The International Thorium Molten-Salt Reactor Developmental activities

Dr. Kazuo FURUKAWA
(QYT00127@nifty.ne.jp)
http://www.ithems.jp/e
http://msr21.fc2web.com/English.htm
International Thorium Energy & Molten-Salt Technology Inc. (IThEMS**, Chairman)*
***International Thorium Molten-Salt Forum (**ITHMSF**, President)*
October, 2010

ITHEMS
アイテムス

- Global Major Technology : 100-200 years life
- Based on the **SYSTEM – PRINCIPLE**
  SYSTEM is "nuclear fuel-cycle system"
  (not "nuclear power reactor")
- "**Simplicity**" ------ reliable ----- "ECONOMY"
- **Flexible System**:
  better is better (best is not best)
  ------ familiar technology

1944: Chicago University (Eugene WIGNER)
Reactor : chem. Engineering system
working medium “LIQUID”
(might be “molten fluoride salts”)

1950- 1980: ORNL (Alvin WEINBERG, MacPHERSON,)
Molten-Salt Reactor PROGRAM

1950- 1976: CRNL (W.B. LEWIS)
Accelerator Breeding : SPALLATOR

1980: JAERI (K. FURUKAWA, K. TSYKADA, Y. NAKAHARA)
Accelerator Molten-salt Breeder (AMSB)

1985: FUJI (fuel self-sustaining simple MSR station)

1988ーー: THORIMS-NES
（***Thorium Molten-Salt Nuclear Energy Synergetic System)***

"Brief HISTORY of Molten-Salt Reactor DEVELOPMENT"

- 1947—76: ***Oak Ridge NL: MSR-Program*** [MS Breeder Reac.(MSBR) development]
- 1965-69: Experimental-Reactor:***MSRE operation*** (total :26,076 hrs, no accident) at ORNL
- 1968-80: USA: Molten-Salt Group (EBASCO, etc.: Reicle, deBoisblanc)
  approached to JAPAN for MSBR develop. (Kamei、Nishibori)
- 1972-83: EdF [Elec. de France]-CEA MSBR program (Bienvenu, Lecocq)
  approached to KF from 1981
- 1980.10 KF etc. invented ***AMSB*** (Accelerator Molten-Salt Breeder).
- 1981 Academic Assoc."Thorium-Energy Research"(:Profs. Kaya, Husimi, Nishibori, Saito etc)
  Parliament Group for Th Energy in Govern. Political.Party(100members)
- 1982.5. The 1st MSR Meeting at EUCHEM-Conf., La Gaillarde, France
- 1982 USSR Journal "Atomic Energy in Abroad" translated the KF paper of AMSB.
- 1983.6 USSR-Kurchatov Inst.（KI）(Direc. Acad. Alexandrov, Dr. Novikov) proposed MSR-Cooperation Development to KF.
- 1985.8 KF etc. : invented the fuel-self-sustainable simple small **MSR *: FUJI***

ITHEMS アイテムス

- 1986.3 USSR-KI decided ***MSR Construc.*** (leader: Dr.Legasov) just before Chernobyl-accident [1988.4: Dr. Legasov died & stopped MSR project]
- 1987.11 EdF decided "no SUPERPHENIX-No.2 (Na-FBR)" (President Bergougnoux) and ***invited KF***. for the Th-MSR examination
- 1988.11 ORNL(Direc.Trivelpiece) proposed to KF the coop. on MSR with USSR..
- 1988.12 KF prepared ***"THORIMS-NES Report"*** at Clamart Inst., ***EdF***,
- 1990.5 USSR-KI (Direc.Velikhov) proposed to KF the coop. on MSR devel. again.
- 1991.7 USSR-Inst.Theo.Exp.Phys.(Chuvilo) invit.KF coop. AMSB-study, & Sosny Sci. Cent.(Chigrinov), Minsk, too.
- 1992.6 US Presi. Bush's Advisor.Sci. &Tech.(**Dr.Allan Bromley**) encour.KF on Th-MSR devel.
- 1995.6 RUSS Fed. ***Inst.Tech. Phys. (ITP), Snezhinsk***. (Direc. Acade.E. **Avrorin**, Dep. Sci. Direc, V, **Simonenko**), proposed the ***coop. devel. of miniFUJI. and accepted by KF***
- 1997.4 ***"Intl Conf. MSR Develop."*****,** at RAND, USA with 24 MSR specialists. from **Japan(5), USA(5), Russia(4), Belarus(2), India, France, Turkey, Czech & IAEA**
- 1997.7 **Japan·USA·Russia Trilat.Coop**.MSR-Dev Meet., decid.miniFUJI-site in ITP, Snezhinsk.
- 1997.8 US Presi. Clinton Advisor Sci.&Tch.(**Dr.J.Gibbons**) promised to KF,
- Japan,USA,Russia Trilat. Coop.MSR-Dev. and Coop. with ORNL: no problem

ITHEMS
アイテムス

- 1998.2 Academ.Avrorin, ITP visit Japan; Russian Govern. approved MSR Coop. plan.
- 1999.12 ***Three Agency Study (OECD/IEA, /NEA, IAEA)*** [**TAS**]: Intl. Devel. of 12 Nuc Pow. St., incl. FUJI.
- 2001.8 pub. Book:"**Revolution in Nuclear Power-Plants**" (Japanese) by KF. in success
- 2002.10. [**TAS**] Report pub.:"Innovative Nucl.Reac.Devel-Opportu. Int.Coop."
- 2003.10 Parliam.Group of Govern.Party invited KF on Th-energy policy.
- 2004.5. IAEA "Status-Rep. Innov. Small & Medium Sized Reactor Design"
  (2004.10. our 3rd draft was sent to IAEA), will be pub.Oct.,2006
- 2004.9 Czech & Slovakia Visit: , Rez NRI; Pilzen SKODA; Brno; Slovakia Nucl. Ene. Conf..
- 2005.8 Compreh.Rep. "New Primary Energy by Th MSR Tech." Elec.Chem.73 (2005) 552.
- 2005.9 R.Moir & Edward Teller: Nucl.Tech.151 (2005) 334. supporting FUJI concept.
- 2006.2 GIF-MSR Steer.Comm.Meeting, at OECD, Paris (observer: KF)
- 2006.6 "**Nucl.Non-Prolif.**" by KF awarded **Prize of Excellence** from Nobel Peace Prize Winner Eisaku Sato (the former Japan. prime minister) Foundation."

- 2006.9 **SKODA-JS**(Pres. M.Fiala) invited KF to the 50 years anniversary
- 2007.1. **IAEA-TECDOC-1536**: "Status on Small Reactors without On-site Refuelling" published including "FUJI concept"**.(p.821-856)**
- 2007.8. ***ICENES*, Istanbul, Turkey: " Road Map Realiz. Global-scale Th Breed. Fuel Cycle by Single Molt.-Fluoride Flow", 18 coauth. [Ene. Conv. & Manag., 49(2008)p.1832-1845.]**
- 2008.6. 21st Int.Conf.ECOS 2008, Poland: present. 2 **papers by Prof.Erbay(Turkey) et al.**
- 2008.10. Joint Int. Conf. on MS:MS08, Kobe, Japan: presented.
- 2008.10. **Formal NPO: ITHMSF** (Int. Thorium Molten-Salt Forum) was established.
- 2009.4. Taiwan Inst. Nuclear Eng. Research (INER) engineers visited Furukawa
- 2009.4. Adv. Nucl.Fuel Manag.(ANFM IV),Th-fuel Sec. South Carolina,USA: present 2 papers
- 2009.4. visited Venezuela, and discuss. with USA colleagues at Los Angeles.
- 2009.5. discuss with Dr. A. Bjorseth, Chairman of SCATEC, mother comp. of Thor Energy.
- 2009.6 visit Prague and Moscow for miniFUJI & FUJI development task plan
- 2010.3 present. at "Th Energy Alliance" Conf., March 29-30, 2010, Mountain View, CA, USA
- 2010.6 started the new company: **International Thorium Energy & Molten-Salt Technology Inc. (IThEMS): President K.Fukushima, Chairman K. Furukawa**
- 2010.9 visiting Czech: IThEMS and Czech side signed momorandum for collaboration towards the realization of a miniFUJI in practical use ina near future.

“Revolutionary Strategy for Our Target : THORIMS-NES

(Thorium Molten-Salt Nuclear Energy Synergetic System)”

Dr. Kazuo FURUKAWA

(QYT00127@nifty.ne.jp)

http://www.ithems.jp/e

http://msr21.fc2web.com/English.htm

International Thorium Energy & Molten-Salt Technology Inc. (IThEMS**, Chairman)*

***International Thorium Molten-Salt Forum (**ITHMSF**, President)*

October, 2010

ITHEMS
アイテムス

Agenda

- A. Basic Principle of Fission Energy Industry Technologies:

  "Nuclear Fuel-Cycle" is much more important than "Reactors"

- B. Selection of specific Fuel-Cycle System:
- C. Path to realize the Th-U Breeding Fuel-Cycle:
- D. Development strategy for realizing the "Simplest" Th-U Breeding Fuel-Cycle:
- Conclusions:

ITHEMS アイテムス

A. Basic Principle of Fission Energy Industry Technologies:

(1) "Establishment of Breeding Nuclear-Fuel Cycle" is crucial:

- The **doubling time (Td)** for fission fuel industry growth **in about 10 years** (cf. the next-page Figure) for establishing the requested fission fuel breeding cycle.

-Necessary for Global Survival-

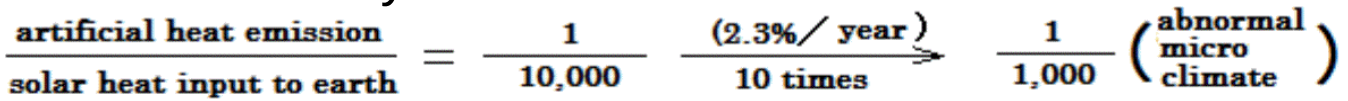
- Only require 10,000 tons of the consuming fission fuel per year for 10-TWe (10 billion kilo), with its establishment:

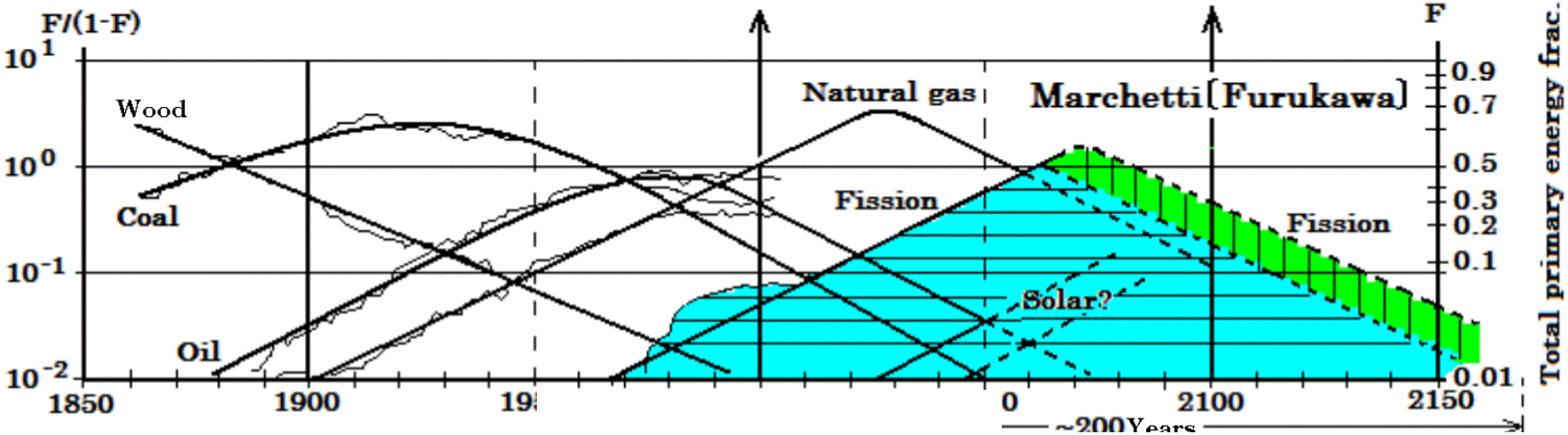
➔ Nuclear waste can be drastically reduced.

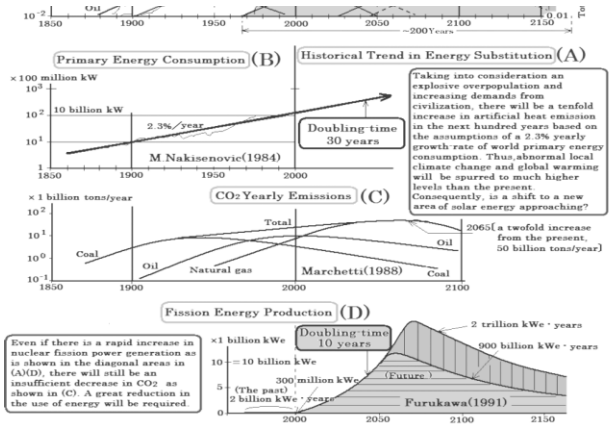
“Global Future Energy Prediction”

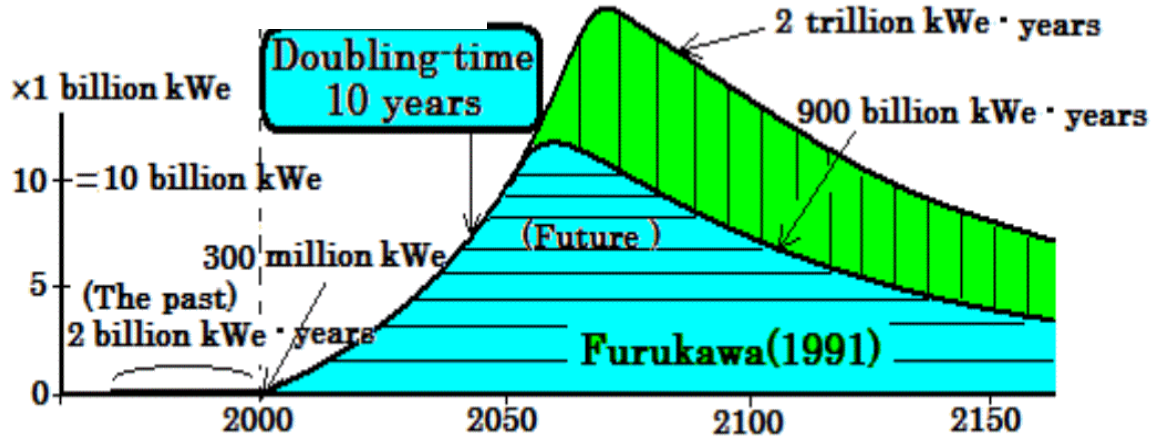
Logistic Function

The basic problem: ***disordering of major energy technology***, Application of **solar-based technology**: Needs 100 years more









ITHEMS アイテムス

A. Basic Principle of Fission Energy Industry Technologies:

(2) Breeder Power Reactor system is too "utopian":

- Breeding Cycle should be achieved by a **Symbiotic system**:
- FISSION process is: ***Energy rich***, but Neutron poor
  "Fission Breeding Power Reactor" is insufficient
- SPALLATION process: Energy poor, but ***Neutron rich***
- A symbiotic system couples:
  Good converter of Fission Power Reactors with
  Good fissile producing Spallation Reactors
- "Near Breeder" ("Self-sufficient nuclear fuel system"):
  -Most simple, most stable and **very high safety**-
  ➔ the ideal NUCLEAR POWER STATION !

ITHEMS アイテムス

B. Selection of specific Fuel-Cycle System:

(1) Uranium - Plutonium (U-Pu) breeding fuel-cycle is the subsidiary technology of early stage of the development:

- **Disadvantages** of SOLID-FUELed U-Pu Breeding Fuel-Cycle
  - nuclear proliferation ---**plutonium**
  - nuclear waste ----**trans-U elements**
  - possibility of severe accident (core melt-down) ---**weak safety**
  - economical difficulties due to:
    "fuel-assembly fabrication & handling",
    "complex reprocessing", "necessity of huge-size", etc.

- Huge investment in the past 60 years, but not successful in realizing an effective Breeding Fuel-Cycle:

- But, its contribution will remain until the middle of this century.
  ➔ The accumulated technology has made launching the new technology easy and feasible:

ITHEMS アイテムス

C. Path to realize the Th-U Breeding Fuel-Cycle:

(1) Establishment of the Nuclear-Fuel Cycle (NFC) as "Chemical Engineering Devices" (1/2):

- What **Dr. Eugene WIGNER** predicted in 1944 was that:
  - REACTOR: Nuclear Chemical-Reaction Energy System should be **"Chemical Engineering Devices"**
  - Its working medium should use a **"FLUID"** as the nuclear fuel and as coolant
  - An ideal nuclear power reactor would be probably "the *molten-fluoride salt fuel* reactor" later developed by ORNL, USA under his successor: Dr. Alvin Weinberg

ITHEMS アイテムス

B. Selection of specific Fuel-Cycle System:

(2) The Thorium - Uranium (Th-U) breeding fuel-cycle is the most promising approach:

- Superiority of the "Th-U" over the "U-Pu" system is extensively recognized in these days:
- One of the superiorities:
  Almost none of "the trans-U elements" is produced:
- Weak point:
  No "natural fissile nuclide" available with this "Th-U":
  ➔ Alternative solution available:
- The "Th-U" system should be the mainstream of the development strategy:

ITHEMS アイテムス

C. Path to realize theTh-U Breeding Fuel-Cycle:

(1) Establishment of the Nuclear-Fuel Cycle (NFC) as "Chemical Engineering Devices" (2/2):

- Thorium utilization in "SOLID-FUEL REACTORS":

  High Temperature Gas-cooled Reactors (HTGR) and
  Light- or Heavy-Water Reactors (LWR or HWR) etc.

  - Not suitable for practical "Th-U" cycle development due to the strong gamma rays associated with U232:

  - Difficulties of Chem.-Processing and Fuel-Fabrication

ITHEMS アイテムス

C. Path to realize the Th-U Breeding Fuel-Cycle:

(2) Fissionable material procurement:

- Thorium is a fertile material and
  has no fissile nuclide such as U235 or Pu239/241:
- Slightly enriched or denatured uranium can be used for the initial fuel:
  (Plutonium produced will be of relatively low concentration and small in amount):
- Plutonium from spent uranium solid-fuels,
  resulting by simplified FREGAT processing (no fuel-assembly and fabrication)
- Eventual elimination of the plutonium stockpiles:

ITHEMS アイテムス

C. Path to realize the Th-U Breeding Fuel-Cycle:

(3) Realization of Breeding Fuel-Cycle by selecting the Symbiotic system:

- The **key factors** for establishing the full scale breeding fuel-cycle:
  - ➔**Implementing** the comprehensive improvement and maintenance of the

    "Accelerator Breeding System" (SPALLATOR)

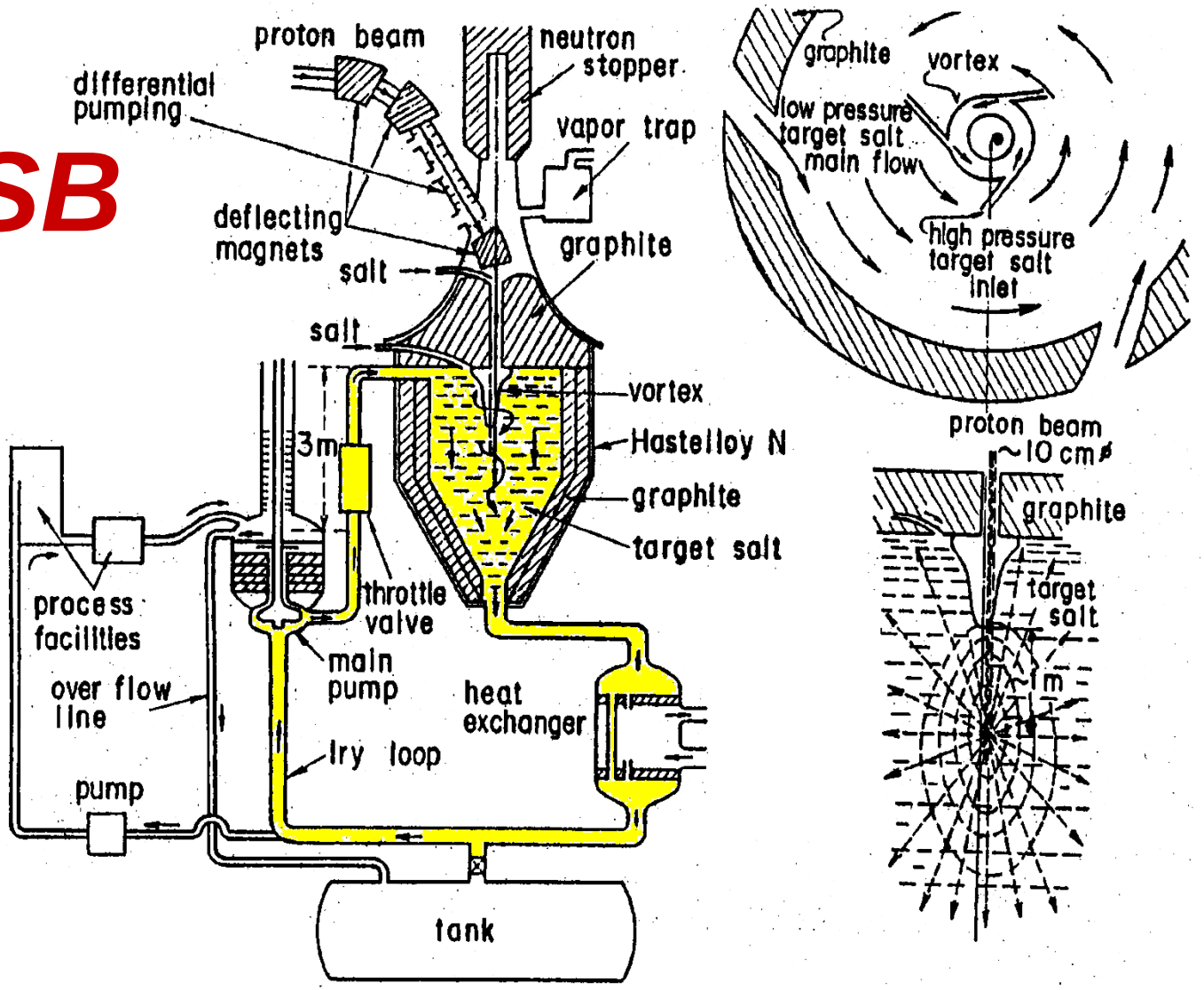
- Successful development of the

  "Accelerator Molten-Salt Breeder (AMSB)" invented by K.F. et al. on 1980 (cf. the next-page Figure)

  - ➔**Solving** the technical difficulties of:
    - intensive radiation-damage &
    - localized intense heat generation etc.:

Accelerator Molten-Salt Breeding Facility

AMSB



ITHEMS アイテムス

D. Development strategy for realizing the "Simplest" Th-U Breeding Fuel-Cycle:

(1) Basic principle of new technology:

- CANADIAN PLAN in realizing the "Th-U Breeding Fuel-Cycle":

  Solid-fuel high conversion-ratio "CANDU" + "Accel. Breeder" was considered by Dr. W. B.Lewis (1950-1980)

  ➔Not realistic to achieve a simple breeding cycle system.
  Recent Canadian plan: "CANDU + FBR" is much worse

  ➔INDIA is in a similar situation at the moment

- THORIMS-NES concept based on Breeding Fuel Cycle by the "*Single* Molten-Salt Liquid Phase" to be implemented:
  (MSR: *FUJI*) + (Accelerator Molten-Salt Breeder: *AMSB*)

ITHEMS アイテムス

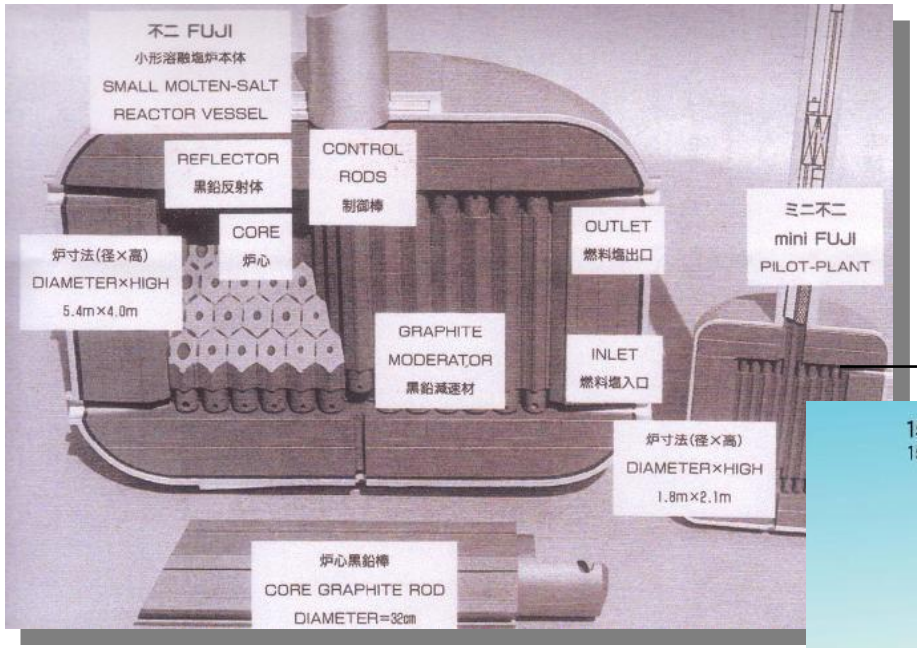
D. Development strategy for realizing the "Simplest" Th-U Breeding Fuel-Cycle:

(2) Idealistic "Thorium - Molten Salt Reactor" system (1/2):

- Proposed **Thorium-Molten Salt Reactor,**
  "FUJI": ***near breeder*** (cf. the next-page Figure)

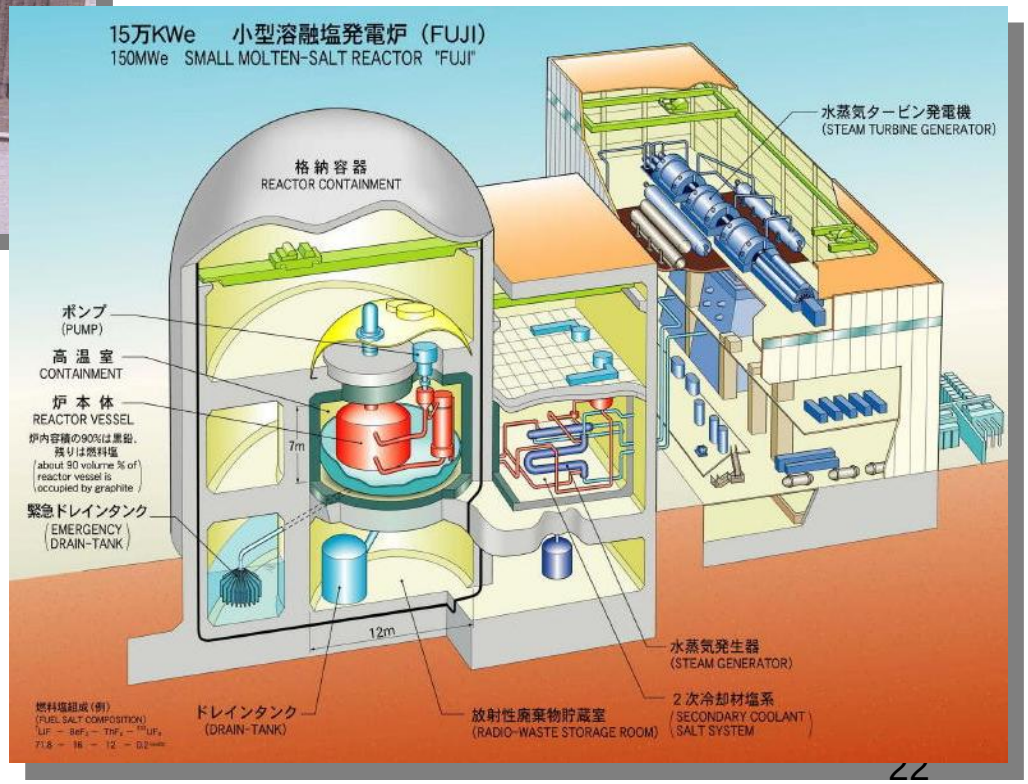
- **Simplified Structure**, easy to operate and maintain:
  - Almost ***fuel self-sustaining*** ,
  - Even small power size: 150-300 MWe
    without continued chemical processing & core-graphite replacement
- **Simple Reactor Vessel:** Simple ambient pressure tank with no big-flange, only one control-rod and no fuel-handling:
- **Factory manufactured:** Small size & modular arrangement:
  Excellent economical advantages (Continued)

Molten-Salt Power Reactor



FUJI

Cross-section View of **FUJI** and **miniFUJI** Reactor Vessel Models



Inside: **Graphite** is only **90 % vol.**
Almost **no Control-rod**.

Full View of FUJI Molten-Salt Reactor

ITHEMS アイテムス

D. Development strategy for realizing the "Simplest" Th-U Breeding Fuel-Cycle:

(2) Idealistic "Thorium – Molten Salt Reactor" system (2/2):

- For the 1st stage operation fuel:

  Plutonium from existing **warheads stockpiles** and **Solid-U-fuel reactors** aiming at the reduction and eventual, **total**, elimination of plutonium

- For the 2nd stage operation fuel:

  Production of **U233** for **many new reactors: FUJI**

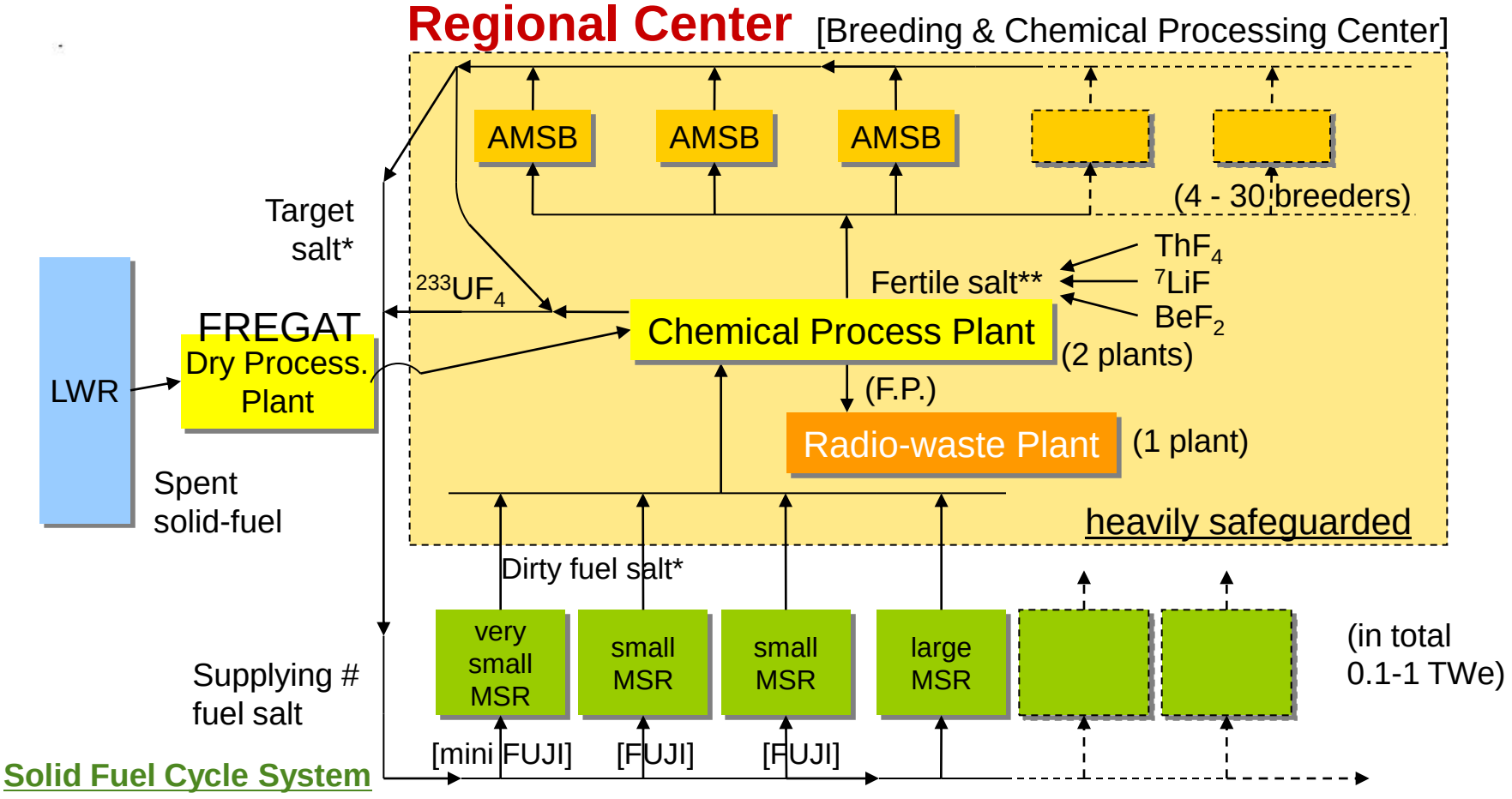
  by launching many "**AMSB**" Timetable: about 3 decades

- "**Regional Centers**" : 20-30 locations in the world (cf. next Fig.)

  to handle the "chemical processing" of the spent fuel salts:

  ➔ *"U233 producing AMSB"* and *"Nuclear Waste Plants":*

Thorium Molten-Salt Breeding Fuel-Cycle System



(*) ^{7}LiF-BeF_2-ThF_4-$^{233}UF_4$ (**) ^{7}LiF-BeF_2-ThF_4 (#) target salt* + additive $^{233}UF_4$

ITHEMS アイテムス

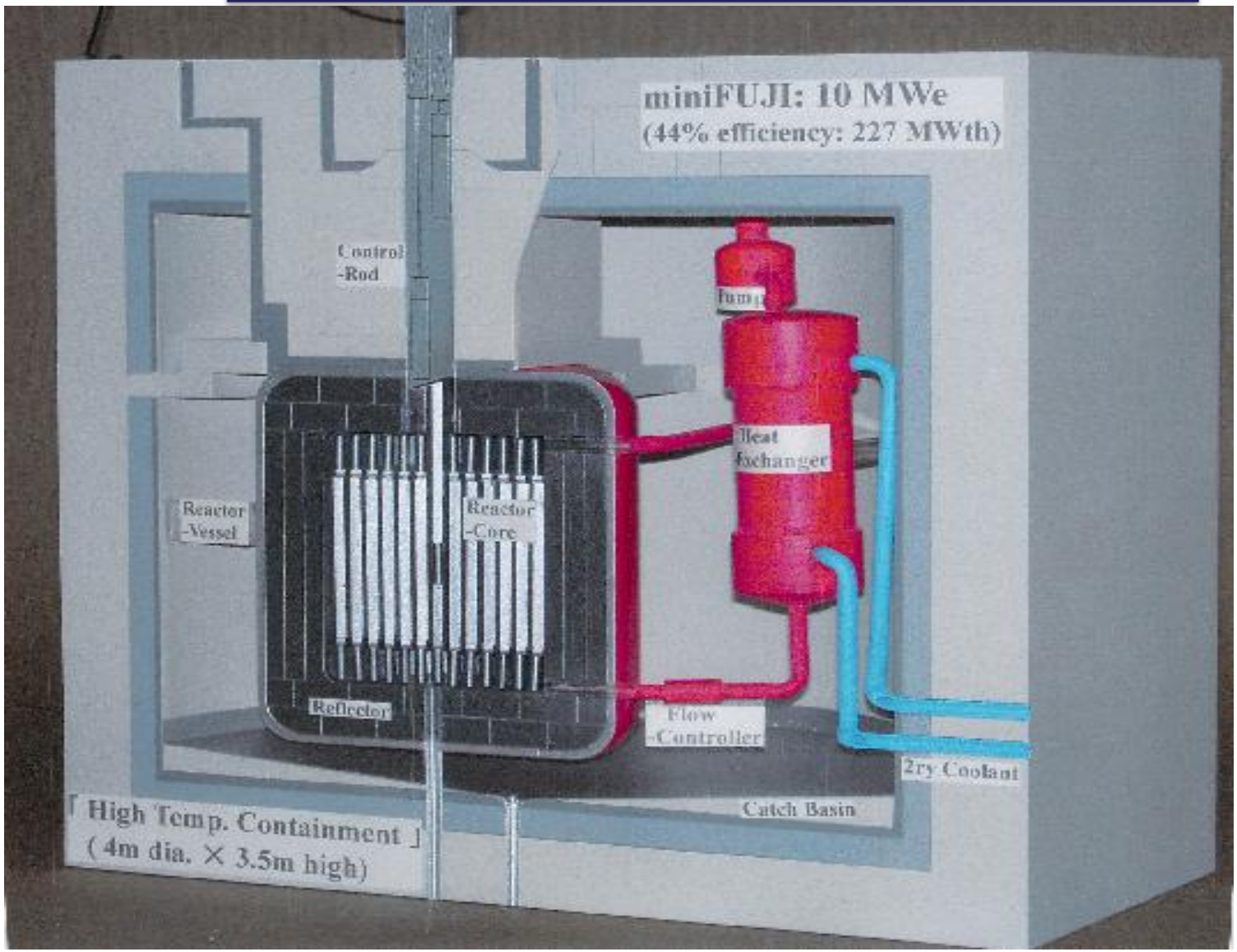
D. Development strategy for realizing the "Simplest" Th-U Breeding Fuel-Cycle:

(3) THORIMS-NES is feasible in the Shortest Period with Minimum Development Cost:

- Concept based on the review of *R&D results for past 70 years*:
- "Small-sized nuclear power station: *in minimum investment*
  - by using the past excellent R&D results
  - by international cooperative partnership with private companies"
  - by the support of liquid-sodium technology experience
- *MSRE operation* at ORNL for 4 years:
  - equivalent to the fuel-burning for 10 years at "FUJI" already
- Investment estimated:
  - $0.3B for "miniFUJI" reactor for the next 5-6 years:
  - $1.5B for "FUJI" reactor for the next 12 years from now:
  - $20B for AMSB development at "Regional Centers" worldwide for 25 years (starting 10 years later) from now

ITHEMS
アイテムス

Model of miniFUJI in "High Temperarure Containment"



ITHEMS
アイテムス

Conclusions

- Excellent advantages of THORIMS-NES:
  - Safety (No "core meltdown" accident in principle)
  - Radioactive-waste no production of trans-U elements
  - Nuclear proliferation protection: no Pu
  - Economy (simple structure and operation, etc.)

    which should result in a conclusive public acceptance
- "The simpler is the better."
- Promising potentialities for launching by (small-fund & short-time)

  the huge-sized new nuclear industry throughout the world.
- Significant contribution to the realization of

  "Co-existence & Co-prosperity Society" on earth

ITHEMS
アイテムス

"Thorium Molten-Salt NuclearEnergySynergetic System-THORIMS-NES" Concept of realizing "Co-existence & Co-prosperity Society" on earth

Promising potentiality for launching the huge-sized New Nuclear Industry throughout the world.

"THORIMS-NES"

- No "Plutonium" production
- No "Core meltdown"
- Small-sized Nuclear Reactor
- *Safety, *Radioactive-waste, *Nuclear proliferation, *Economy
- "Liquid" fuel

LWR, HTGR etc.

- "Solid" fuel
- "Plutonium" production
- "Core Meltdown" "Re-criticality" possibility
- Huge-sized Nuclear Reactor

- "Establishment of **Breeding Nuclear-Fuel Cycle**" is crucial:
- "Breeding Power Reactor system" is too "utopian" and not effective:
- "U-Pu" Breeding Fuel-Cycle is the subsidiary technology for early stages of the development:
- Realization of the most promising **symbiotic "Th-U" Breeding Fuel-Cycle**:

ITHEMS
アイテムス

Thank you for your attention

Dr. Kazuo FURUKAWA