GIF High Temperature Materials – MSR Aspects

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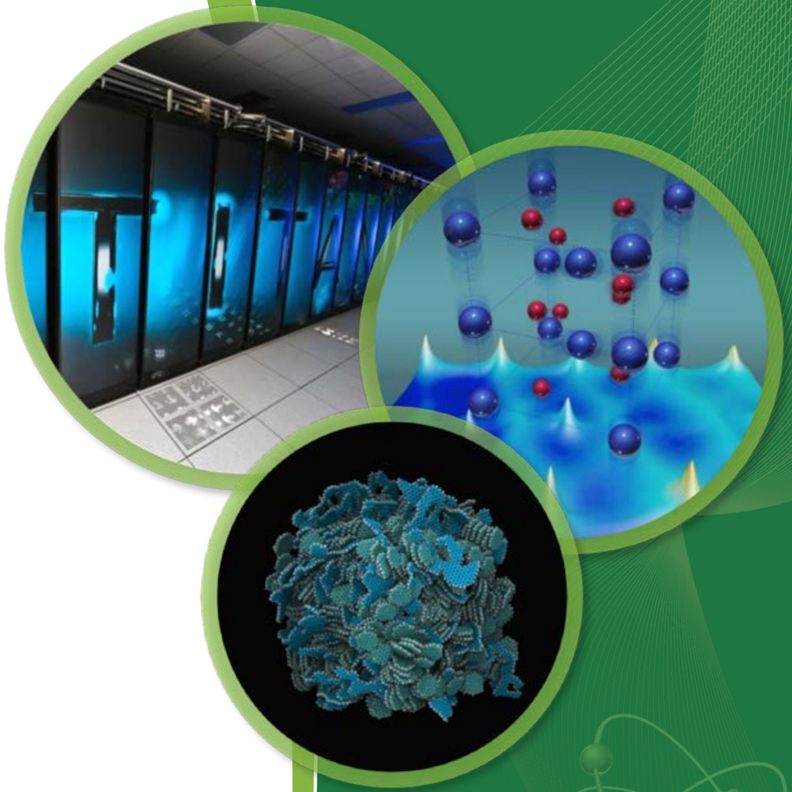

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Acknowledgments

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Molten Salt Reactor materials R&D can leverage advancements worldwide in other reactor concepts.

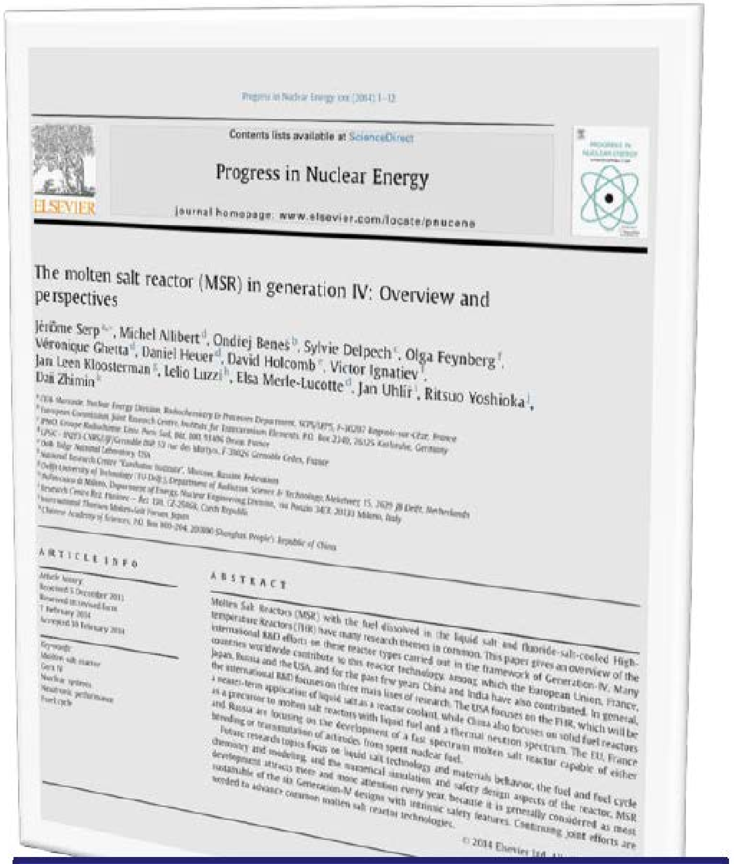
^{7}Li Cost	• Innovative separation technique – ongoing ORNL LDRD • Higher separation coefficient materials
Tritium Management	• DOE-NE project to demonstrate tritium mitigation techniques • Sparging, membrane walls, trapping, and double walled heat exchangers being considered
Structural Ceramics	• SiC channel boxes for BWRs • SiC leaf springs for LWR fuel assemblies • ASTM and ASME standards
Safety & Licensing	• DOE-NRC join initiative on advanced reactor design criteria • ANS standards on liquid and solid fuel MSR design safety
Fuel Cost and Qualification	• SiC & Mo accident tolerant cladding for LWRs • TRISO fuel testing for gas reactors

Several countries are cooperating on liquid and solid fueled MSRs through the GIF process.

- **Molten Salt Reactors have two primary subclasses – dissolved and solid fuel**
  - ➢ **FHRs are solid fuel MSRs**
  - ➢ **TMSR program include solid fuel and liquid fuel MSRs**

- **France, EU members, Russia, China, Japan, Korea, and the US participate through the MSR System Steering Committee**
  - ➢ **Pre-commercial nature of the reactor class promotes open sharing of research results**
  - ➢ **Safety, economics, and proliferation resistance have separate collaborative efforts**

- **Other countries have supportive technology development efforts**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The molten salt reactor (MSR) in generation IV: Overview and perspectives

Jérôme Serp, Michel Allibert, Ondřej Beneš, Sylvie Delpech, Olga Feynberg, Véronique Ghetta, Daniel Heuer, David Holcomb, Victor Ignatiev, Jan Leen Kloosterman, Lelio Luzzi, Elsa Merle-Lucotte, Jan Uhlíř, Ritsuo Yoshioka, Dai Zhimin

2014 Overview of MSR & FHR Technology and Cooperation

Metallic materials of interest to MSR are studied in different countries for multiple reactor concepts.

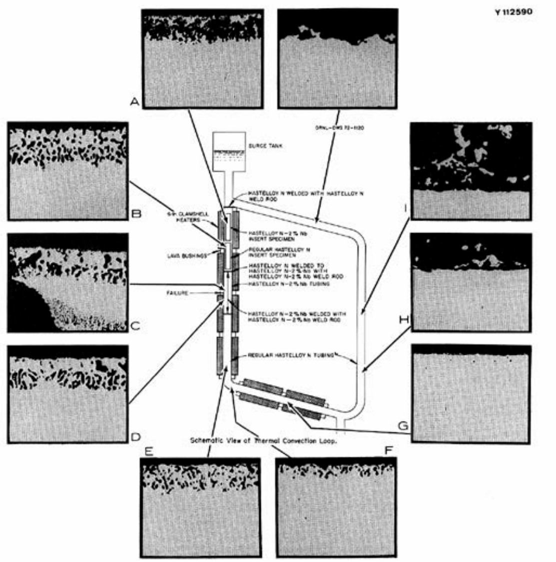

Fig. 11. Micrographs of tubing and specimens from loop 1255 exposed to LiF–23 mole % BeF_2–5 mole % ZrF_4–1 mole % ThF_4–1 mole % UF_4 molten salt at 560–700°C for 9.2 years. As polished. 500×. Reduced 15%.

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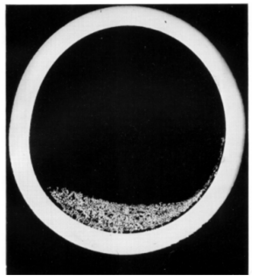


Cr deposits in loop cold leg

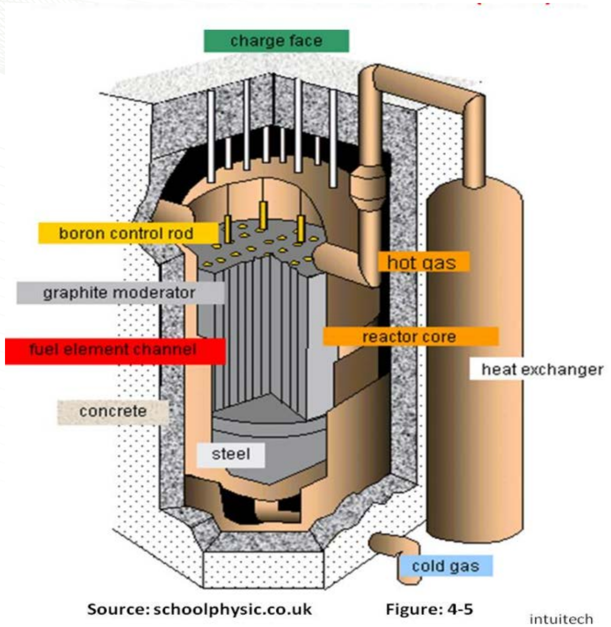
- **VHTR candidate material 316SS is under investigation for FHR application.**
  - Considered as substitute of Alloy N for cost efficiency by academia and industry.
  - Some corrosion concerns are under investigation.
  - 316SS with Ni cladding may provide a solution.
- **Alloy 800H is identified as VHTR candidate material and also proposed for FHR consideration.**
  - ASME BPVC temperature coverage extension for VHTR underway.
  - Discussion on cladding Alloy 800H with Ni for a combination of high temperature resistance and corrosion resistance.

Different GIF member countries can cover a lot more alloys of interest to MSR development.

The mastering of MSR technically challenging technology will require concerted, long-term international R&D efforts – GIF Annual Report 2015

Ni-Mo Alloys Tested by Russian Federation (wt.%)											
Alloy	N	HN80MTY	6	12	16	22	29	30	32	34	36
Cr	7.5	6.8	5.1	7	7	7.5	7.1	7.1	7.1	5	7.1
Mo	16.3	13.2	12.3	12.3	12.3	13.2	11.8	12.2	12.1	12.1	12.1
Ti	0.26	0.93	0.63	—	1.82	1.71	0.56	0.56	0.57	0.95	0.94
Fe	3.97	0.15	<0.33	<0.33	<0.33	0.18	<0.33	<0.33	<0.33	<0.33	<0.33
Mn	0.52	0.013	<0.1	<0.1	<0.1	0.013	<0.1	<0.1	<0.1	<0.1	<0.1
Nb	—	0.01	—	0.96	—	0.98	1	1	1	—	—
Re	—	—	—	—	—	—	—	1.08	—	—	—
Y	—	—	—	—	—	0.01	—	—	0.001	—	—
Si	0.5	0.04	≤0.05	≤0.05	≤0.05	0.053	≤0.05	≤0.05	≤0.05	≤0.05	≤0.05
Al	0.26	1.12	2.39	—	—	0.015	—	—	—	1.5	1.6
W	0.06	0.072	—	—	2.2	—	—	—	—	—	—
C	0.05	0.025	0.006	0.005	0.005	0.003	0.007	0.021	0.004	0.006	0.016

Graphite materials for MSR are also considered by different countries for multiple reactor concepts.



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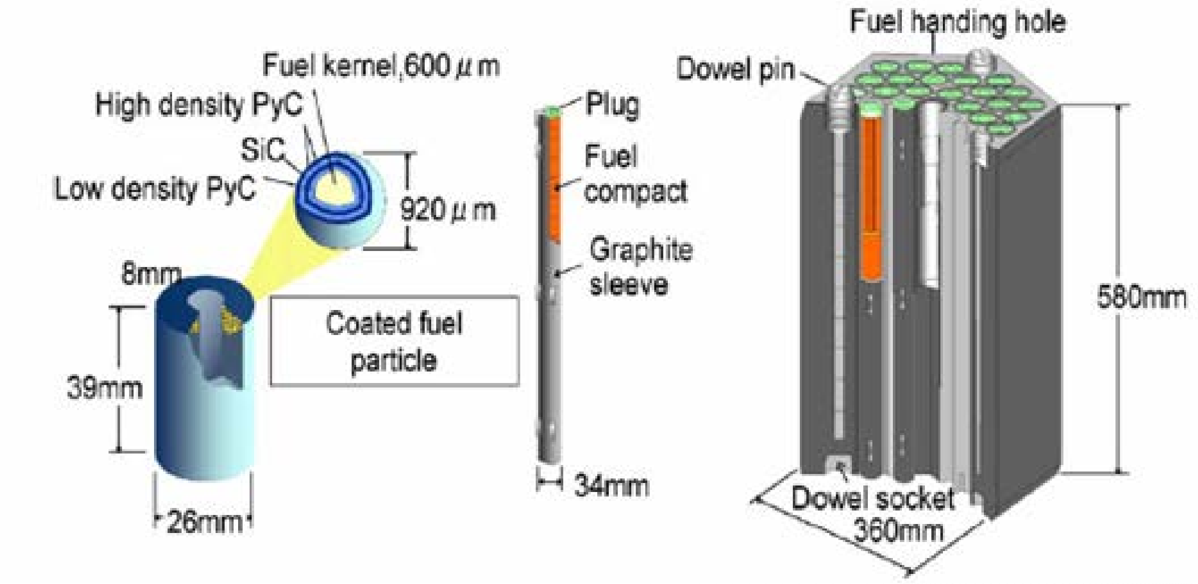
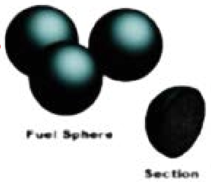


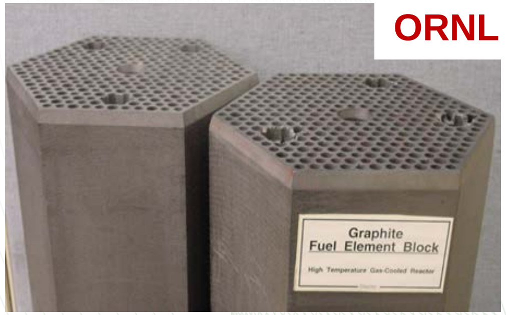
Fuel compact Fuel rod Fuel element

- **Advanced gas-cooled Reactors (AGR)**
  - **British design, CO_2 coolant**
- **High Temperature Gas Cooled Reactors (HTGR)**
  - **Prismatic design**
  - **Pebble bed design (PBMR)**
  - **He coolant**

Fuel pebbles



ORNL



http://hoainamk3.blogspot.com/2010/11/high-temperature-gas-cooled-reactors.html

Several reactor concepts share some common challenges to graphite presence in the core.

- **Effect of fast neutron irradiation and its relationship with microstructure**
  - ➢ **Dimensional changes, structural damage**
  - ➢ **Change in mechanical and thermal properties**
  - ➢ **Change in chemical resistance to environmental effects**

- **Chemical environment effects and surface reactivity**

Gas-cooled reactors

- ❖ **Acute oxidation**
  - o **Air or water ingress (accident conditions) – should never happen**
- ❖ **Chronic oxidation**
  - o **Moisture in coolant will cause slow by continuous oxidation during normal operation – will always happen**

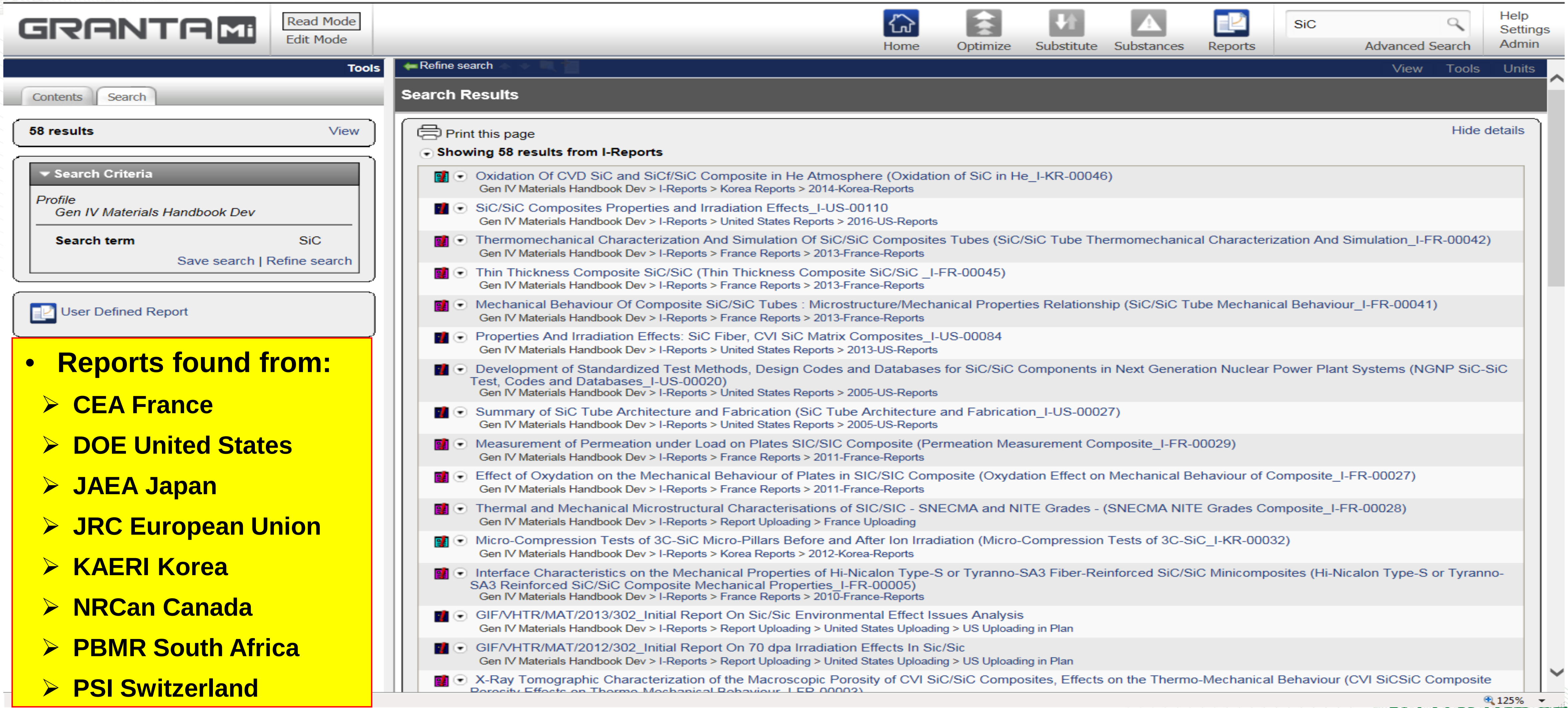
Fluoride-cooled reactors

- ❖ **Tritium control**
  - o **Tritium is produced mostly from Li in the salt**
  - o **May accumulate in graphite**
  - o **Pebbles might be used for tritium chemisorption and removal from the core**
- ❖ **Salt infiltration in graphite**
  - o **May cause structural changes, hot spots in graphite**
  - o **May require sealing of graphite porosity (based on MSRE experience) or coating with protective layers (pyrolytic carbon)**

SiC/SiC composites are potentially applicable to multiple reactor concepts including MSR/FHR.

Reactor Concept	Application	Operating Condition	Project / Design Examples	Possible Deployment
Fusion	• Blanket structures • Various functions	• He, Pb-Li • 400-900°C • >50 dpa	• ARIES • EU-PPCS • DREAM	• Long-term
HTGR VHTR	• Reaction control systems • Core support	• He • 600-1100°C • Up to ~40 dpa	• NGNP • PBMR • GT-HTR300C	• Near-term
LWR	• Channel box • Grid spacer • Fuel cladding	• Water • 300-500°C • ~10 dpa	• PWR (WHC) • BWR (EPRI)	• Mid-term? (ATF)
FHR AHTR	• Core structures • RCS	• Liquid salt • ~700°C • >10 dpa	• AHTR • DOE IRP • SMR's	• Long-term
SFR	• Core structures • Fuel cladding/support	• Liquid sodium • 500-700°C • >100 dpa	• CEA	• Long-term
GFR	• Core structures • Fuel cladding/support	• He • 700-1200°C • >100 dpa	• CEA • GA EM^2	• Long-term

A keyword search by "SiC" in the Gen IV Materials Handbook returned 58 reports from 8 Signatories.



- **Reports found from:**
  - **CEA France**
  - **DOE United States**
  - **JAEA Japan**
  - **JRC European Union**
  - **KAERI Korea**
  - **NRCan Canada**
  - **PBMR South Africa**
  - **PSI Switzerland**

International collaboration in MSR development is gradually gathering momentum under GIF.

- **Eight governments officially expressed intention for international collaboration in MSR development.**
- **Materials R&D is an important part of the collaboration.**
- **With nearly 10 years of MSR/MSRE experience to share, U.S. actively seeks collaborations in MSR/FHR development.**

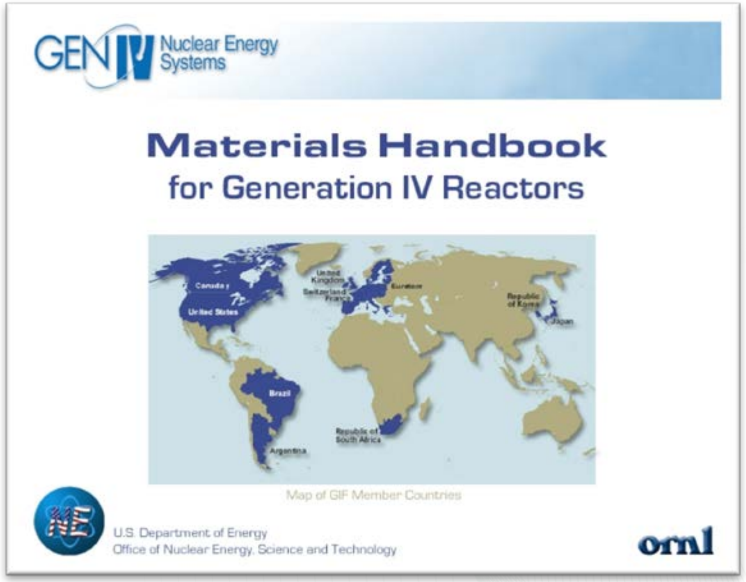
Status Of Signed Arrangements or MOU and Provisional Co-operation Within the Gen IV International Forum (GIF) as of 31 December 2015							
EU	France	Japan	China	Korea	Russia	Switzerland	US
Signatory	Signatory	Observer	Observer	Observer	Signatory	Signatory	Observer

- **Australia also joined the GIF MSR System Steering Committee in 2016.**

Materials R&D for MSR development can efficiently leverage existing infrastructure developed for GIF.

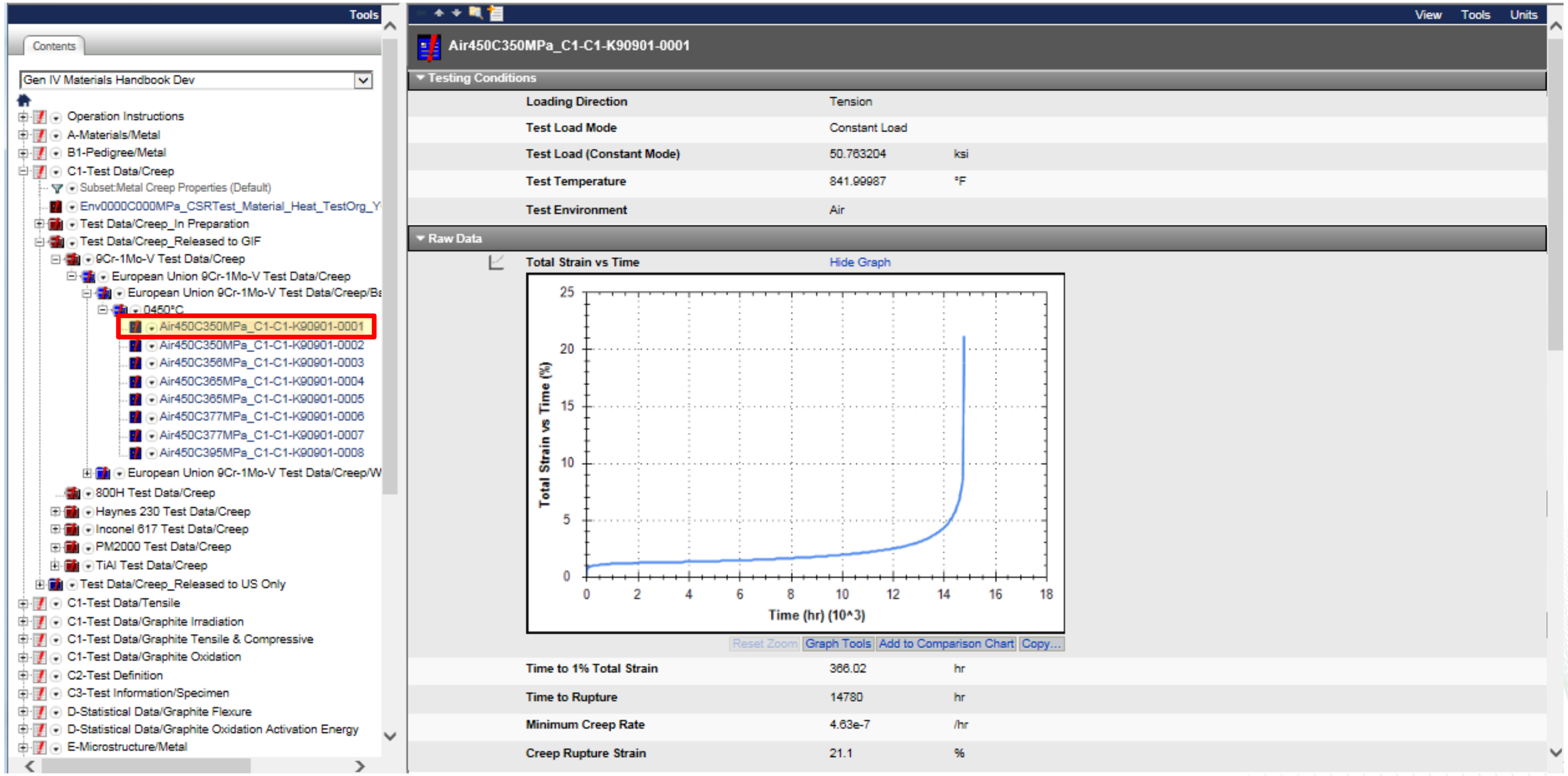
Gen IV Materials Handbook, a digital relational materials database system, is developed to facilitate international collaborations.

- **Started business operation in 2009.**
- **To collect and manage an estimated $180 million total worth of high temperature structural materials data.**
- **R&D reports and materials test data contributed from 9 Signatories for VHTR development.**
- **Developed by Oak Ridge National Laboratory and sponsored by U.S. Department of Energy.**
- **Its infrastructure allows efficient development of subject-matter-specific digital database for MSR materials.**



A tangible framework enables sharing R&D workload among signatory countries – an example.

Collaborating countries can focus on specific issues, respectively, for a technical topic of common interest, and achieve synergistic accomplishments in a HLD.



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Summary

- **Several candidate metallic, graphite, and composite materials for MSR are of common interest to many countries.**
- **International collaboration in MSR materials is gathering momentum under GIF, and further organizational efforts are needed to make it more effective.**
- **The U.S. MSR materials R&Ds actively seek collaborations with industry and international partners for synergism to strive for cost- and time-efficiency.**
- **ORNL is willing to share its MSRE experience and modern technologies for industrial and international collaborations in MSR materials R&Ds.**

THANK YOU FOR YOUR ATTENTION.

Contact: Weiju Ren, renw@ornl.gov, 865/576-6402

BACKUP SLIDES FOR DISCUSSION USE

The Handbook accommodates materials data in formats from different countries for collaboration.

A master data record layout is designed for all attributes of different countries.

Red Country
Blue Country
Yellow Country

Attribute 1	
Attribute 2	
Attribute 3	
Attribute 4	
Attribute 5	
Attribute 6	
Attribute 7	
Attribute 8	

Attributes (i.e. parameters) in two colors are used by two countries.

Red Country Data Entry

Attribute 1	134
Attribute 2	
Attribute 3	85
Attribute 4	678
Attribute 5	
Attribute 6	2
Attribute 7	
Attribute 8	

Blue Country Data Entry

Attribute 1	
Attribute 2	54
Attribute 3	
Attribute 4	
Attribute 5	346
Attribute 6	
Attribute 7	456
Attribute 8	90

Yellow Country Data Entry

Attribute 1	
Attribute 2	54
Attribute 3	
Attribute 4	678
Attribute 5	
Attribute 6	
Attribute 7	456
Attribute 8	

The Handbook can hide the empty attributes in data display.

Red Country Record Display

Attribute 1	134
Attribute 3	85
Attribute 4	678
Attribute 6	2

Blue Country Record Display

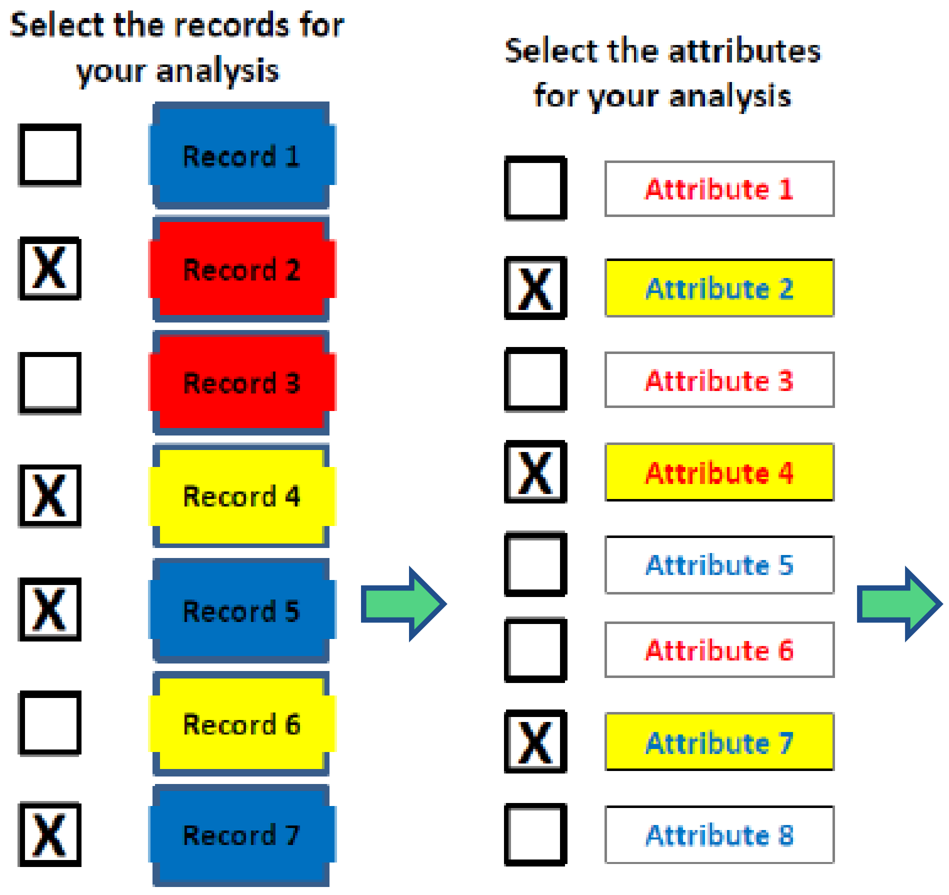
Attribute 2	54
Attribute 5	346
Attribute 7	456
Attribute 8	90

Yellow Country Record Display

Attribute 2	54
Attribute 4	678
Attribute 7	456

Each country still has their original data displayed.

Tools are provided to combine materials data from different countries for analysis and study.



Red Country
Blue Country
Yellow Country

Present data for your analysis at a click of your mouse!

	Attribute 2	Attribute 4	Attribute 7
Record 2		678	
Record 4	45	946	456
Record 5	67		375
Record 7	86		901

Data gaps are clearly identified.

Compare data of Attribute 2 from Yellow and Blue Countries.

An agreement was signed by each Signatory to contribute materials test data for R&D synergism.

GENERATION IV INTERNATIONAL FORUM

PROJECT ARRANGEMENT
ON MATERIALS
for

THE INTERNATIONAL RESEARCH AND DEVELOPMENT
OF THE VERY-HIGH-TEMPERATURE REACTOR
NUCLEAR ENERGY SYSTEM

APPENDIX 2 Database

A database established by the PMB will be created as a repository of data for all work packages of the Project, to ensure close coordination of testing programs between each task for generation of new data.

The generation / assembly of required data will be accomplished within each task. Each Signatory representative participating in the VHTR Materials Project shall be responsible for transferring all data and files generated under specific tasks of the Project Plan into the database. It is currently planned that the database of the VHTR Materials Project will be a joint database. A committee established by the PMB will oversee management of the database. The database development and implementation will be included as a portion of the contribution of one or more Signatories.

The database will be used to retain and assemble existing data provided by the Signatories, data available in the literature, and other resources. The VHTR Materials database will be used to assemble and coordinate the extent of testing, addressing security and access issues, track various types of testing, test conditions, product forms, metallographic information, minimize redundancy of testing, assess and rank quality of test data, and to preserve data for current and future use.

Content of the Database

- Data generated during the Project ,
- existing data provided by Signatories,
- data available in the literature or other databases,
- data from other sources.

… The VHTR Materials database will be used to assemble and coordinate the extent of testing, addressing security and access issues, track various types of testing, test conditions, product forms, metallographic information, minimize redundancy of testing, assess and rank quality of test data, and to preserve data for current and future use.