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清华大学 核能与新能源技术研究院
Institute of Nuclear and New Energy Technology, Tsinghua University



中国核能行业协会先进核能制造经验交流会

甘肃 武威

GIF 框架下国外的先进制造合作

孙立斌

2022年8月23

清华大学 核研院



汇报主要内容

1. 快速回顾 AMME-ITF 年初 昌江
2. 一份调查问卷及结果分析
3. 一个案例 eVinci 复合材料鉴定
4. 一点思考

TMSR-LF1



Prototype MSR - TMSR-LF1 is under construction in China

Overview of Gen-IV developments and Generation IV International Forum (GIF)
SNETP Forum 2021, 2-4 February 2021

1. 快速回顾 AMME-ITF 年初 昌江 (1)



GEN IV International Forum

先进制造与材料工程临时任务组 情况报告

Advanced Manufacturing and Materials Engineering Task Force (AMME-ITF)

孙立斌
清华大学 核研院
2022年1月12日
海南 昌江

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2021年活动 AMME活动情况

背景参见—Gif年度报告2020 P74-75

Meeting

- ① 17 Feb 2021
- ② 05 Mar 2021
- ③ 25 Mar 2021
- ④ 22 Apr 2021
- ⑤ 10 May 2021
- ⑥ 23 Jun 2021
- ⑦ 12 Jul 2021
- ⑧ 20 Jul 2021


Workshop

- ◆ 8-9 Nov 2021

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Name	First Name	Function
EDWARDS	Lyndon	Chair
MESSNER	Mark	Co-chair
COSTA	Davide	Secretary
POUCHON	Manuel	Member
SUN	Libin	Member
ZHANG	Lefu	Member
CAI	Xiangzhou	Member
JIN	Ming	Member
REN	Lixia	Member
ABONNEAU	Eric	Member
OKAJIMA	Satoshi	Member
WARD	Caleb	Member
NILSSON	Karl-Fredrik	Member
STORER	Andrew	Member
VAN ROOYEN	Isabella J	Member
PARK	Jeong-Yong	Member
GIROUX	GIROUX, Pierre-François	Member
TEYSSEYRE	Sebastien	Member
IVAN	Lucian	Member
LOWE	Shehan	Substitute
KAMIJI	Yu	Member



Lyndon Edwards
Professor, National Director, Australian Generation IV International Forum Research (ANSTO) and Australian representative of the GIP Policy Group

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从一个真实的工程案例谈起……

先进制造与材料工程 AMME

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AM Materials Development

Westinghouse has funded material development and irradiation performance testing for 316L SS, Ni Alloy 718 and Zr

- Produced AM block and micro-tensile test specimens
- Irradiating materials in MIT's test reactor (Oct. 2014 → 2018)
- Completing post-irradiation examination (PIE) at Westinghouse Churchill laboratory (316 and 718 completed, Zr PIE DOE funded)
- AM 316L irradiation performance consistent with wrought

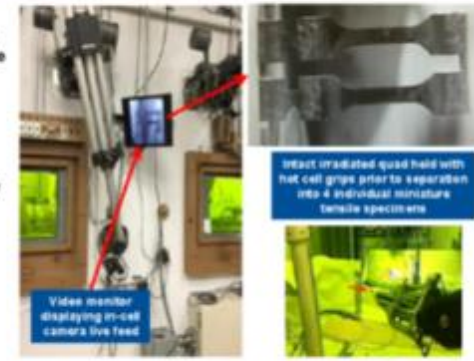


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Mechanical Testing Irradiated AM Specimens

- Unirradiated and irradiated tensile testing of AM 316 SS and Alloy 718 materials inside WEC hot cell
- Room Temp and elevated Temp (i.e., 572° F) tensile testing of ~50 AM 316SS specimens and ~50 AM Alloy 718 specimens
- Extensive unirradiated and irradiated materials evaluations completed



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1. 快速回顾 AMME-ITF 年初 昌江 (2)



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Reactor Ready Component Project

Kaizen Event Held to Select Demonstration Component – Dec 2014

- Thimble Plugging Device (TPD) selected as the first AM Fuels component to be placed in a commercial reactor as a demonstration component
- Low risk component, moderate complexity, fully contained in guide thimble tubes.
- AM TPD is equivalent in Form, Fit and Function as existing TPD.

Completed testing, analysis, quality assurance, manufacturing qualification, licensing, etc. to support one production AM TPD

Working with Exelon, the AM TPD was delivered for the Byron Unit 1 Spring 2020 Outage via 10CFR50.59

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eVinci™ Microreactor Primary Heat Exchanger (PHX)

eVinci PHX AM Design / Concepts

- Developed lattice support structure for HX header plates
- Flexible supports allow tube movement during thermal cycle

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NRC AMT Action Plan Deliverables Currently Publicly Available

First US Application of Additive Manufacturing

- Standard Plugging Device
- Installed in March 2020 in Byron Unit 1
- First additive steel – L-PBF
- Strong line safety significant enhancement from ASME BAFI Code Case
- Code-Case
- Implementation with installation
- Installation done without prior NRC approval under 10 CFR 50.59

Second US Application of Additive Manufacturing

- Channel Fastener
- Installed in April 2021 at Browns Ferry Unit 2
- First additive steel – L-PBF
- Non-ASME BAFI Code Case
- ASME enhancement with installation
- Installation done without prior NRC approval under 10 CFR 50.59

- Task 1A: Laser Powder Bed Fusion TLR and technical assessment [ML 20151A292](#)
- Task 1B: Cold Spray TLR [ML 21203A107](#)
- Task 1B: NDE Gap analysis [ML 20048A012](#)
- Task 1C: Modeling and Simulation of Microstructure
 - Gap analysis to predict microstructure [ML 20288A307](#)
 - Gap analysis to predict material performance [ML 20350B000](#)
- Task 2A: 10 CFR 50.59 process [ML 21200A202](#)
- Task 2B: Assessment of regulatory guidance [ML 20213A083](#)
- Task 2C: Guidelines Document
 - Draft AMT Review Guidelines [ML 21074A037](#)
 - Draft Guidelines Document for AM-L-PBF [ML 21074A040](#)
- Task 3D: NRC Workshop on AMTs for Nuclear Applications
 - NRC 2021-03: [Part 1](#), [Part 2](#)

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材料供应商的制造资质

设计单位认可：设计单位编制产品性能要求
质量标准和**组织试验考核**等工作

监管部门许可：取得国家核安全局
核电主设备材料供应商资质

仅为材料供应商，需要后续工艺配合
与主装备制造单位相关的工艺评定

创新改变世界 科技创造未来

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AMME挑战

- 知识产权 IP
- 许可 Licensing
- 最终，需要实验数据来鉴定新技术

Ultimately, experimental data will be needed to qualify new technologies

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AMME机遇

- 需打破“传统”核发展循环—寻找能够实现部分目标的**较短循环**
- 需抓住机会，为开发、部署和许可创建**新的框架**—对于许多先进的反应堆设计和许多材料，尚处于未知领域
- 国际（区域）合作**开发新技术验证/鉴定通用数据平台
- 与监管机构合作/沟通**：我们是谁，我们想做什么，我们面临什么挑战，我们的路线图…

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1. 快速回顾 AMME-ITF 年初 昌江 (3)



2022年AMME计划和展望

1. Plan future workshops
2. Organise activities in the GIF Industry Forum 2022
3. Plan and implement collaborative R&D initiatives
4. Coordinate with other groups investigating or promoting advanced manufacturing for advanced reactor manufacture



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AMME启发和思考

- 中国参与GIF同仁在AMME议题上面临的挑战和机遇
- 如何**自我认知**
- 如何开展全方位多层次的**合作**（国内/国际、跨堆型）
- 如果整合资源，激发能动性，真正做到科技创新上的
跟跑 → 并跑 → 领跑
- 拟充分利用核能行业协会和Gif中国的平台资源，建议今后**邀请安审单位**代表参会讨论。



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2. 一份调查问卷及结果分析 (1)

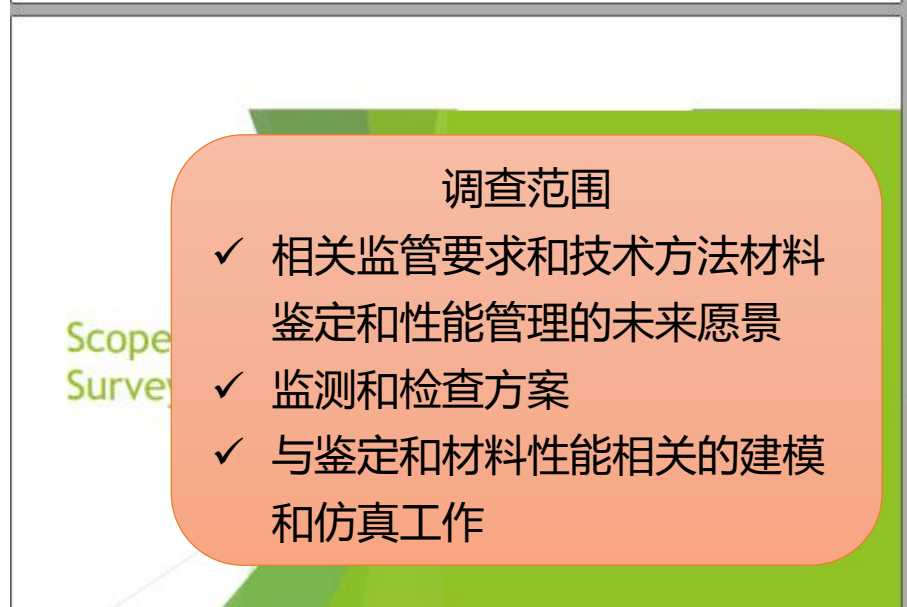


确保先进反应堆中材料的适当鉴定和全寿期性能常见监管实践：调查结果



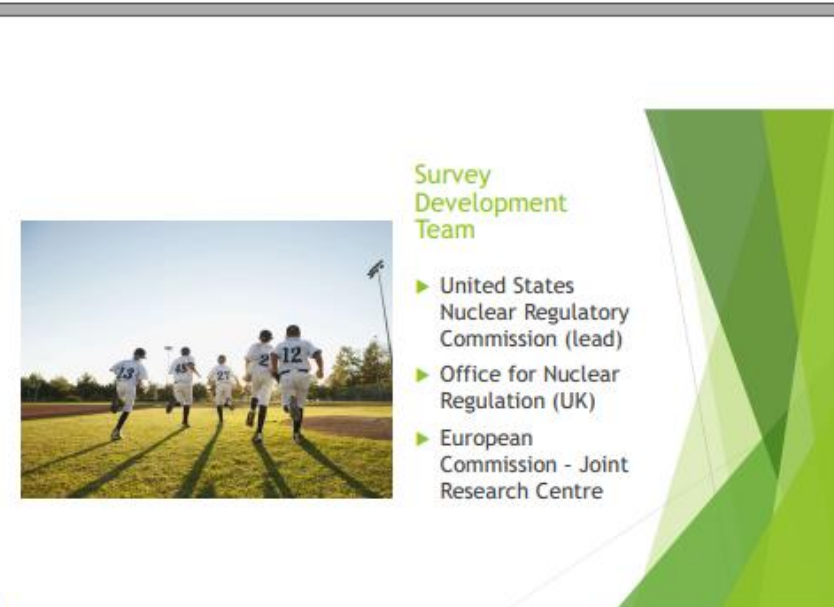
调查目的

- ✓ 解决先进反应堆材料和组件的许可、监管问题
- ✓ 材料鉴定和性能管理的未来愿景
- ✓ 当前监管实践、技术方法、方法和模型，以确保适当



调查范围

- ✓ 相关监管要求和技术方法材料鉴定和性能管理的未来愿景
- ✓ 监测和检查方案
- ✓ 与鉴定和材料性能相关的建模和仿真工作



Survey Development Team

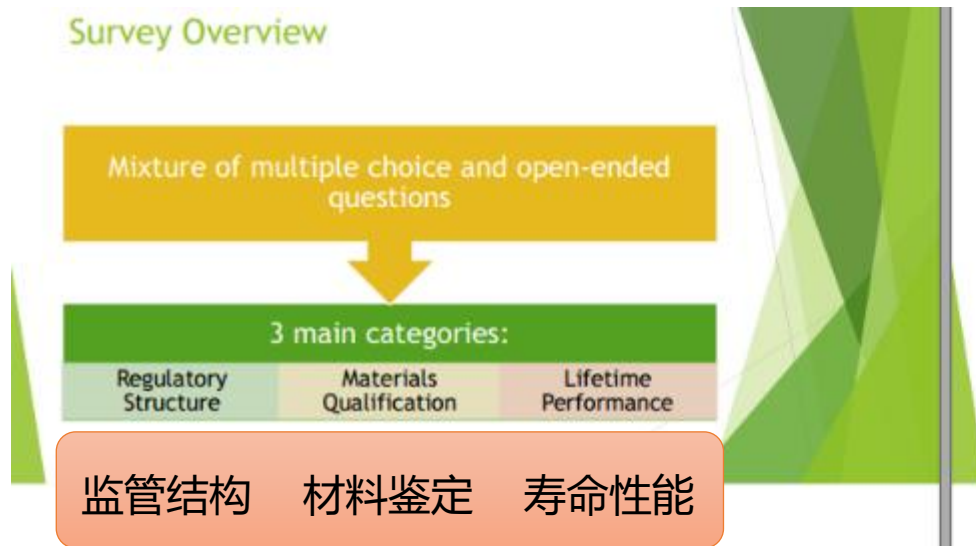
调查研发团队小组

- ✓ 美国NRC牵头
- ✓ 英国ONR参与
- ✓ 欧盟EC-JRC参与

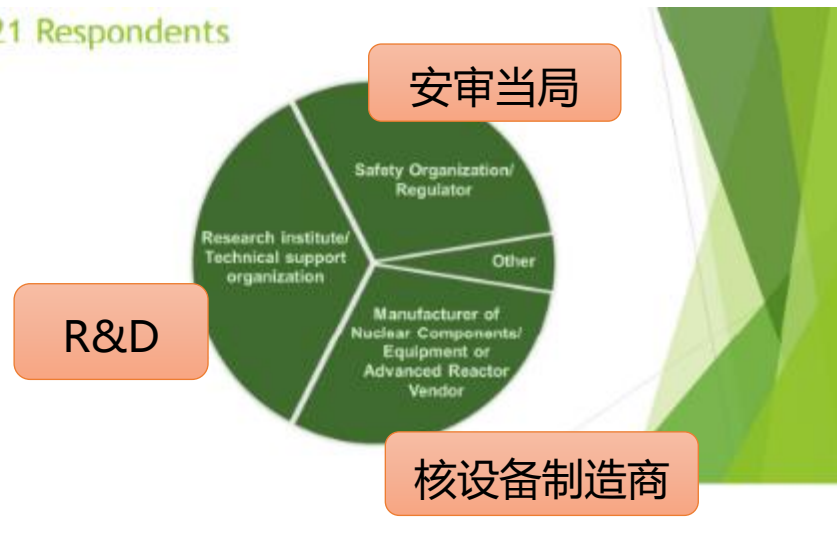
2. 一份调查问卷及结果分析 (2)



Survey Overview

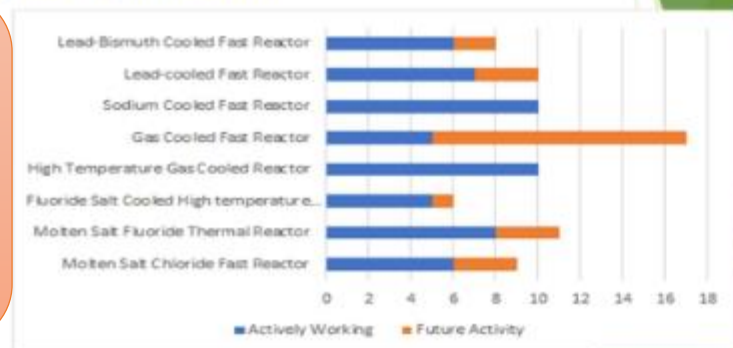


21 Respondents

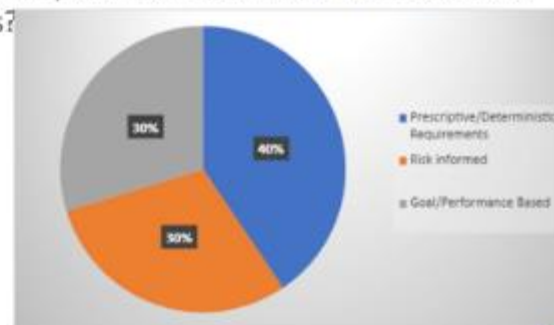


Q4: What reactor types are of interest to your organization?

1. 气冷快堆
2. 熔盐氟化物热堆
3. 铅/钠冷快堆 & 高温堆



Q5: What is the current regulatory framework used to ensure appropriate qualification and through life performance of materials in advanced reactors?



当前用于确保先进反应堆中材料的适当鉴定和寿命性能的监管框架是什么?

- 确定论方法
- 风险指引
- 基于目标/性能

2. 一份调查问卷及结果分析 (3)

Q7: Which Design and Fabrication Codes/Standards are being used by your organization?



采用的规范和标准

Q8: Organizations can have different levels of involvement in the development of codes and standards. Please describe your organization's involvement in the development of codes and standards.



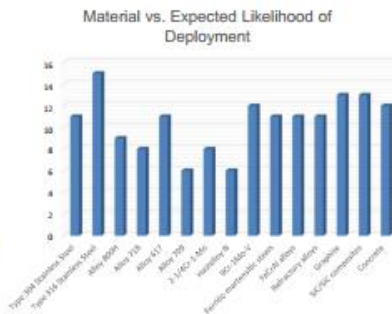
被调查者组织参与制定规范和标准情况

关键收获——监管结构

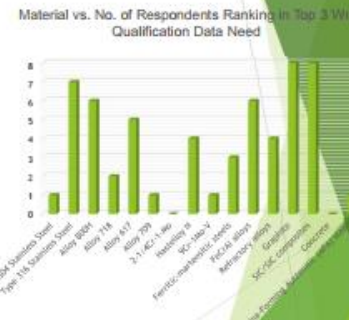
Key Takeaways - Regulatory Structure



Q10: Which materials will likely be deployed in advanced reactors in the next decade? Check all that apply.



Q11: Please select 3 materials that will have greatest data needs for qualification/approval in advanced reactor designs.



Q10未来十年哪些材料最可能会被用于先进反应堆? 316, 石墨, SiC复合。

Q11 选3种在先进反应堆设计中对鉴定/批准数据需求最大的材料。石墨, SiC复合, 316。

2. 一份调查问卷及结果分析 (4)



Qualification of AM Components

21. Would you qualify an AM component rather than a material?



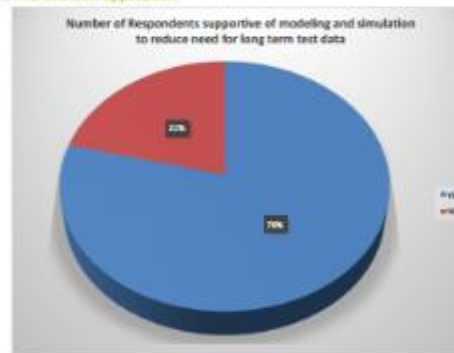
22. If yes, is AM component qualification a part of Regulatory Framework?



Q21 鉴定AM组件比材料更合格?

Q22 AM组件鉴定是否属于监管框架的一部分?

Q30: Would your organization consider the use of modeling and simulation to reduce the amount of long term testing data required in a licensee application?



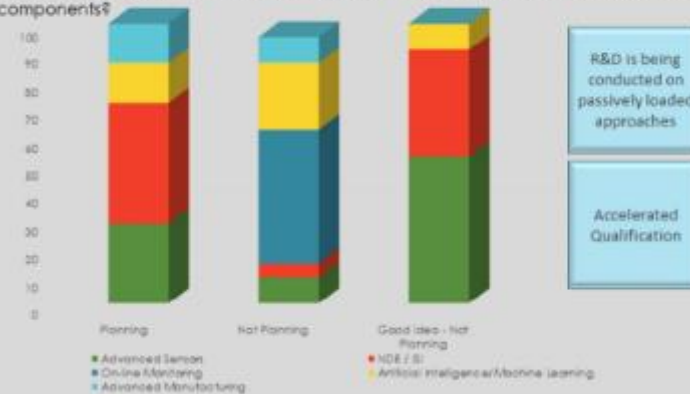
是否会考虑使用建模和仿真来减少被许可方应用程序中所需的长期测试数据量?

23. What would your organization expect to be included in a test program for materials that may be subjected to a non-water environment (e.g., molten salt, molten lead)?



希望将哪些内容包括在可能受到非水环境影响的材料的测试计划中?

27. Are you developing regulations, procedures or guidance on the application of advanced sensors and non-destructive examination techniques for in service inspection or online monitoring of passive components?



是否正在制定关于在役检查或无源部件在线监测中应用先进传感器和NDE的法规、程序或指南

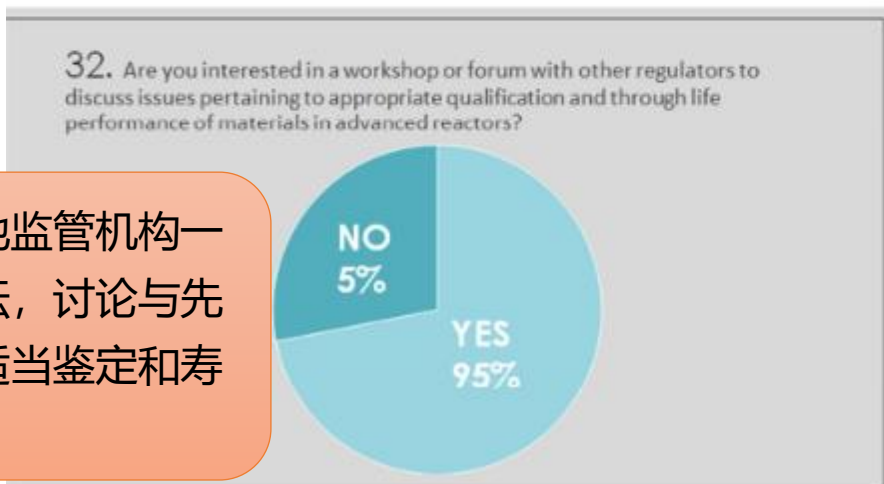
2. 一份调查问卷及结果分析 (5)



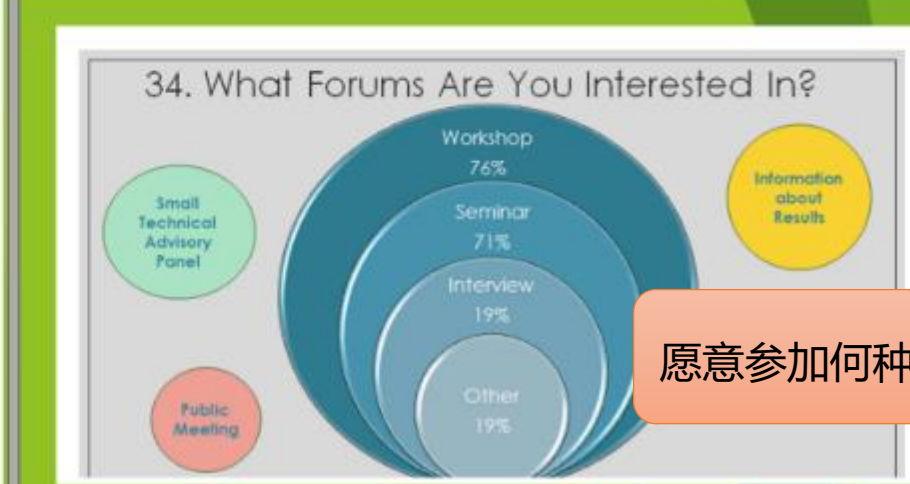
评估组件运行可靠性和材料鉴定的方法与您当前的期望一致?



关键收获-材料鉴定和寿命性能



您是否有兴趣与其他监管机构一起举办研讨会或论坛，讨论与先进反应堆中材料的适当鉴定和寿命性能相关的问题?



愿意参加何种类型的论坛



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4. 一点思考

4.1 如何**高效推进**先进核能制造？

例：高温堆核石墨材料国产化
(熔盐堆、快堆)

金属构筑成形锻件应用

4.2 设计与供应方能力匹配 ✓

监管与设计、制造匹配？

4.3 国内核电项目业主、总包、设计和制造**主动参与**监管和取证前期过程，也希望核能行业协会搭建平台**邀请**安审监管人员以**开放、平等**地参与讨论

例：某年上海INGSM安全局代表参会

4.4 新型的服役前、中、后检测手段

例：燃料元件/国产核石墨CT体积检测

4.5 新材料、新工艺的知识产权 IP保护

例：国产石墨、燃料元件、SG换热管

期望：

上述思考（困惑）能在“**中国核能行业协会先进核能制造经验交流会**”得到响应、探讨和解答。



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清华大学 核能与新能源技术研究院
Institute of Nuclear and New Energy Technology, Tsinghua University



中国核能行业协会先进核能制造经验交流会

甘肃 武威

GIF 框架下国外的先进制造合作

孙立斌

2022年8月23日

清华大学 核研院

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