

Progress of METI project on “advanced fuel components”



Fumihisa Nagase

Japan Atomic Energy Agency

April 11, 2016

Fifth Meeting of the OECD-NEA EGATFL

Overview of projects related to ATF in Japan

- Two projects for basic study and development of SiC composite supported by MEXT (2012 – 2016)
- Three projects for development of ATF (SiC composite, stainless steel, pebble bed fuel) supported by METI (2012 – 2018)
- One project for alloy development and feasibility study of FeCr and FeCrAl ODS ferritic steel as MEXT projects (2013 – 2016)
- New METI project for “advanced fuel components” including ATF components since 2016 which covers development and proof of industrial technologies together with consideration of technology readiness levels for practical use in existing LWRs

Objective of the project

To establish ***technical basis*** for practical use of “advanced fuel components” including accident-tolerant fuel components in existing LWRs

Technical basis:

- Consideration of TRL for LWR use
- Consideration of attribute guide
- Development and conductance of R&D plan

What has been done (Outline of FY 2015)

1. Evaluation of influence of practical use of accident-tolerant fuel components in existing LWRs

- Investigation of current development status of candidate materials
- Review of Technology Readiness Level (TRL) and clarification of technical subjects towards practical use
- Consideration of TRL from design to waste disposal
- Evaluation of influence of implementation by codes for industrial use
 - Influence on core and plant behavior
 - Influence on safety evaluation method such as SA analysis
 - Influence on fuel design and behavior
 - Influence on quality management and standards
 - Influence on transport and storage
- Acquisition of materials data necessary for evaluation
- Clarification of subjects towards practical use (irradiation tests, fuel design, behavior analysis, consideration of fabrication in commercial scale) and preparation of subject map

2. Prioritization of candidate materials and draft research plan

3. Preparation of experiments to obtain data for design ATF assembly

How to progress with project

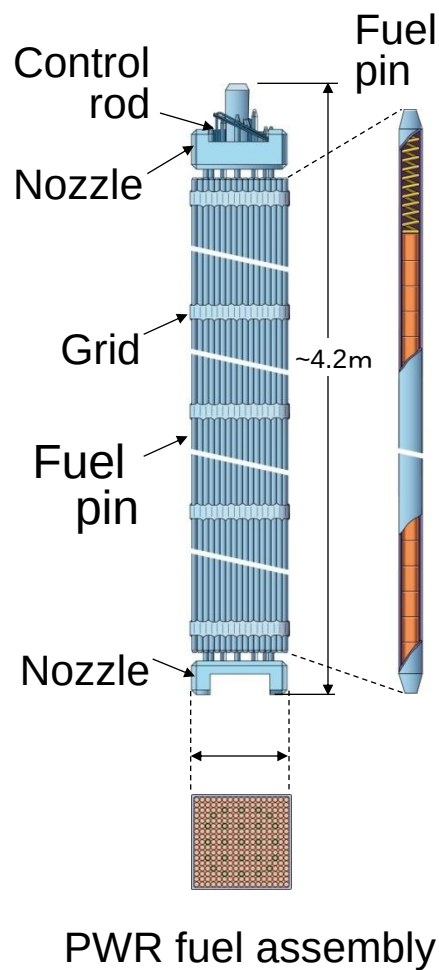
Particularity of LWR fuel rod

- OD: ~10 mm, Length: ~4m, cladding thickness: <1 mm
- Designed considering environment (operation to accident)
- Fabricated with “reactor-grade” specification under severe quality control
- Continuously improved and technologies accumulated for over 60 years
- Design through waste disposal controlled by strict standards and criteria



It is necessary and reasonable
to utilize experience, intelligence, and analytical tools for fuel
design, fabrication, practical use, safety evaluation and
materials development
which have been accumulated in fuel vendors, plant supplier,
research institutes and universities.

Main candidate materials for ATF components



SiC

- ATF cladding for PWR and BWR
- ATF channel box for BWR

In collaboration with MHI, MNF, Toshiba, and Hitachi-GE

TRISO

- Advanced fuel having good compatibility with SiC cladding

In collaboration with NFI

FeCrAl-ODS

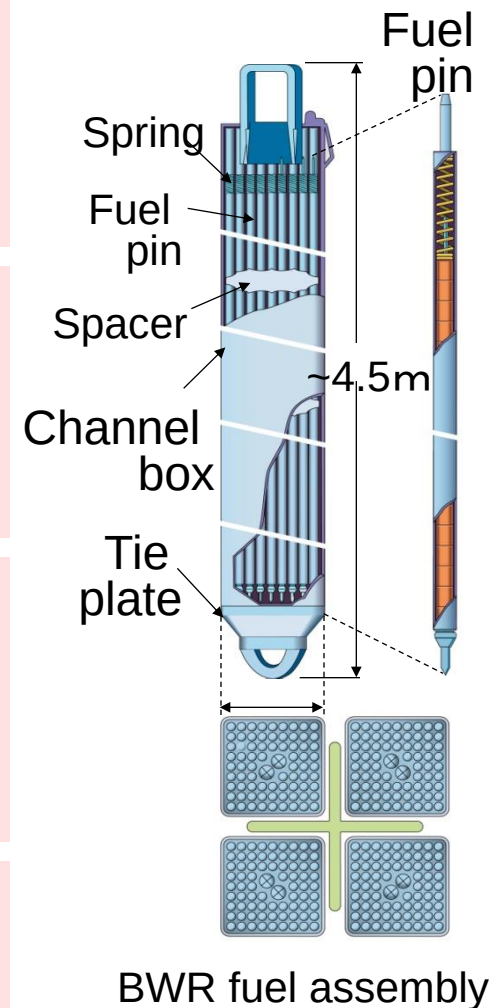
- ATF cladding for PWR and BWR

In collaboration with NFD, GNF-J, Hokkaido univ., Kyoto univ.

ATCR

- Passive safety control blade for BWR and control rod for PWR

In collaboration with CRIEPI and Toshiba



Evaluation of influence of implementation and examination of subjects and data gaps

- Preliminary evaluation of influence of implementation by codes and methods for industrial use, including sensitivity analyses
 - Influence on core and plant behavior
 - Influence on safety evaluation method such as SA analysis
 - Influence on fuel design and behavior
 - Influence on quality management and standards
 - Influence on transport and storage
- As a result, subjects and data gaps for modelling and predicting the ATF behavior under normal operation and accident conditions, designing the ATF fuel and components, etc. were indicated.

Consideration of TRL to develop ATF components and evaluate development stage for LWR use

- To develop ATF components which can be practically used in LWRs, it is necessary to evaluate the influence of use of the candidates in terms of reactor core design, thermo-hydraulic characteristics, safety evaluation, standards and criteria, storage, transport, reprocessing, waste disposal and treatment in addition to fuel design and fabrication technologies.

Stage	TRL	Field						
		Fuel design (Normal & Transient)	Fabrication & Quality management	Core design, thermo-hydraulic	Safety evaluation (DBA, BDBA, SA)	Standards, Criteria	Storage, Transport	Reprocessing, Treatment
Development prior to practical use	9							
	8							
	7							
Technologic demonstrat	6							
	5							

General definition of TRL for practical use of ATF components

TRL		General definition for practical use of accident tolerant fuel materials	
Development prior to practical use	Operation of practical system	9	Commercial use in the power plant – of the accident tolerant fuel material selected as the practical technology – as the technology development defined by the attribute guide – under finally-determined commercial-use conditions
	Verification of practical system	8	<u>Proof of finally-determined commercial-use conditions</u> (Final confirmation of irradiation of Lead Use Assembly (LUA), plant operation, safety analysis, and standards and criteria)
		7	<u>Design completion of products for practical use</u> Validity verification of design as the practical technology (Completion of: – full-scale production of commercial fuel bundle with accident tolerant fuel materials, – irradiation of prototype fuel bundle (LTA: Lead Test Assembly) in commercial reactors, – plant operation under commercial reactors conditions, – safety evaluation, – and establishment of standards and criteria)
Technological demonstration	Proof of industrial technology	6	<u>Final selection of candidate technology for practical use</u> – Performance verification as industrial technology by production test of proto-type fuel bundle with accident tolerant fuel materials, performance verification of fuel materials (irradiation under simulated commercial reactor conditions), etc. – Establishment of standards and criteria which enable synthetic technologies including design of proto-type fuel bundle with accident tolerant fuel materials, core design, plant operation, method of safety evaluation, and transport/storage/waste treatment/disposal
	Development as industrial technology	5	<u>Establishment and verification of production and design technologies for accident tolerant fuel components</u> (by conducting production of proto-type fuel components, irradiation of Lead Test Rod (LTR) in commercial reactors, and test of production units for industrial scale). – Establishment of guideline for standards and criteria, consideration of core design, plant operation and safety evaluation method, and establishment of elemental technologies for transport, storage, waste treatment and disposal.
		4	<u>Establishment of design parameter for proto-type ATF components</u> – Verification of performance in elemental process of fuel fabrication based on practicable technology in industrial scale – Consideration of solution of subjects for the standards and criteria, for the current technologies on core design, plant operation and safety evaluation method, and for current technologies on transport, storage, waste treatment and disposal.

General definition of TRL for practical use of ATF components

TRL		General definition for practical use of accident tolerant fuel materials	
Proof of principal	Proof of feasibility	3	<u>Clarification of subjects and targets of development in industrializing of technologies</u> – <u>Proof of achievable range (upper limit) of practical use</u> (by out-of-pile tests, material irradiation tests, test fabrication, etc.) – Estimation of influence of introduction of ATF components on important subjects (estimation of showstopper candidates) and consideration of solution, concerning the current standards and criteria, core design, plant operation, safety evaluation method, and transport, storage, waste treatment and disposal. – <u>Primary selection of candidate technology for practical use</u>
	Proposal and investigation of elements	2	<u>Clarification of achievable range and applicable range of technologies</u> by database preparation, test fabrication of fuel, various preliminary analysis with current method, and investigation of technical option, etc. Consideration of influence on current standards and criteria, transport, storage, waste treatment and disposal. <u>Confirmation of non-existence of crucial showstopper</u>
		1	<u>Proposal of candidate concept of new fuel components</u> based on investigation of fundamental principal <u>Indication of principally achievable range based on clarification of attribute guide</u>

Specific definition of TRL and evaluation of development for four candidate materials assuming use in PWRs and BWRs

[illegible]

Current TRL of four candidate materials

1. Modified stainless steel including ODS-FeCrAl

- Mostly TRL-3 has been achieved or will be achieved in a short period, in terms of fuel design, fabrication, evaluation of influence of use in LWRs
- The final target of achievable technologies in the practical stage is clearly indicated.

2. SiC/SiC composite

- Mostly TRL-2 has been achieved, namely R&D in TRL-3 are on progress, in terms of fuel design, fabrication, evaluation of influence of use in LWRs.
- Survey of “Showstopper” candidates and solution are most important subjects.

3. LWR use of TRISO fuel

- Mostly TRL-2 has been achieved, in terms of fuel design, fabrication, evaluation of influence of use in LWRs.
- TRISO fuel has been developed as HTGR fuel, therefore, subjects for development are hardly seen in some technical areas.

4. ATCR

- Mostly TRL-2 has been achieved, in terms of fuel design, fabrication, evaluation of influence of use in LWRs.
- Steps for technological demonstration may be streamlined if the current cladding material for CR is available.

Development of attribute guide

- Creation of original attribute guide for the development and performance regimes.
- Refinement of assessment levels “Color code” depending on materials.

カラーコード		定義	判定	評価	判定	評価
NEA の分類	本事業の分類					
	—	非該当				
ブランク	ブランク	データ不足であり特性が特定されていないため、現状ではステータスを判断できないもの				
黒	黒	現行の製品概念では致命的な欠陥であり、現状では解決策が見いだせないもの				
赤	赤	現行の製品概念では致命的な欠陥となりうる可能性があるもの、またはデータを取得するために特殊な技術開発が必要となるもの				
青	青	データは不足しているが現行の製品概念で致命的な欠陥とはならないと考えられるものであり、データ取得にも特殊な技術開発を要さないもの（プロトタイプ燃料設計までに明確にすべきもの）				
	水色	関連するデータはほぼそろっているが、何らかの改良が必要で、それにより再度データを蓄積する必要性が生じる可能性があるもので、致命的な欠陥とはならないと考えられるもの（プロトタイプ燃料設計までに明確にすべきもの）				
	紫	データは不足しているが現行の製品概念で致命的な欠陥とはならないと考えられるものであり、データ取得にも特殊な技術開発を要さないもの（プロトタイプ燃料集合体コンポーネントの試験炉照射までに明確にすればよいもの）				
オレンジ	オレンジ	データはほぼそろっているが、何らかの改良（微修正）が必要なもので、その改良がこれまでのデータに大きな影響を与えないもの				
緑	緑	データがほぼそろっており、プロトタイプ燃料集合体の試験炉照射へ適応可能なもの				

2. 通常運転時	属性 (Attribute)	判定	評価
2.1 炉心・プラント運転 (Reactor operation)	2.1.1 通常運転時のふるまい (Behavior in normal operation)		・確認要であるが、ODS-FeCr で FBR 照射実績、SUS 被覆管で軽水炉照射実績から、大きな支障はないと予測される。
	2.1.2 異常過渡変化時のふるまい (Behavior in AOO: Anticipated Operational Occurrence)		・基本的にはジルカロイと同等の荷重に耐えられるように設計するため、異常過渡時の挙動についてもジルカロイと同程度と予測される。 ・今後評価が必要。
	2.1.3 運転サイクル長 (Operating cycle length (12, 18, 24 months ?...))		・現行の BWR 燃料のサイクル長は維持可能と考えられる。 ・ただし、今後評価が必要。
	2.1.4 反応度制御システムに与える影響 (Reactivity control systems interaction)		・BWR の場合、制御棒はチャンネルボックス外にあるため、制御システムとの物理的な干渉はないと断される。
	運転が燃料被覆管に与える影響 (Effect of load on the overall behavior)		・今後評価が必要。 ・ただし、薄肉化するが、現行ジルカロイ被覆管相あるいはそれ以上の強度を確保するため、特段の問題はないと思われる。
	リーク燃料特有の劣化 (Leakage specific behavior of irradiation degradation with fuel fragments)		・水素脆化がないため、二次脆化は生じない。
	燃料製造欠陥の影響 (例: 燃料筒の傷、局所的な腐食、等) (Impact of fabrication defects on fuel integrity, e.g., scratches on fuel tube, corrosion, etc.)		・ODS-FeCrAl 鋼の製造およびその特性に関するデータは多数存在する。 ・延性材料であり、特段の課題はない。 ・ただし、製造欠陥による影響については情報が不十分のため、今後評価が必要。
	ナールティ (Narrowing penalty)		・被覆管肉厚、ベレット、集合体構成に依存する。 ・製造可能かつ機械設計可能な肉厚の範囲で 5%未満で成立する。 ・ただし、今後 ABWR 炉心での評価が必要。
	(Hydriding behavior)		
	2.6.5 浸食 (Erosion)		・現在進めている ODS-FeCrAl の高温水中試験においても異常なエロージョン腐食は示していない。 ・ただし、詳細は今後評価が必要。
	2.6.6 クラッド付着 (Crud deposition)		・過去の BWR においてステンレス被覆管が使用された際に、被覆管に起因するクラッド異常は報告されていない。 ・ただし、詳細は今後評価が必要。
	2.6.7 熱水力特性 (DNB 特性) (Thermal-hydraulic interaction (DNB issue))		・現行ジルカロイ被覆管と同じ外径とするため、特段の違いはない。 ・ジルカロイで培ってきた情報、評価手法を活用するものと判断される。

判定	評価
	・ODS-FeCrAl で試験が進められている。 ・FeCrAl、ODS-FeCr では照射の影響が小さいことがわかっており同程度と予測される。
	・特段の違いはない。 ・燃料棒内の酸素ポテンシャルが高くなりやすい可能性あり。 ・ただし、詳細は今後評価が必要。
	・ODS-FeCrAl で試験が進められている。 ・FeCrAl、ODS-FeCr では照射の影響が小さいことがわかっており同程度と予測される。
	・ODS-FeCrAl で試験が進められている。 ・FeCrAl、ODS-FeCr では照射の影響が小さいことがわかっており同程度と予測される。
	・ODS-FeCrAl で試験が進められている。 ・FeCrAl、ODS-FeCr では照射の影響が小さいことがわかっており同程度と予測される。
	・FeCrAl を含めてデータ蓄積中である。 ・FeCrAl では炉外評価、照射下試験において良好な特性を示していることから大きな問題はないと予測される。
	・一部合金については炉内、炉外試験データあり。該合金組成の確認データが必要である。
	・原理的に特段の問題は考えられないが、PIE 等を実施の際には確認する必要がある。
—	—

Based on the results from TRL consideration and attribute guide, remaining R&D subjects were extracted.

In addition, short-term and long-term R&D strategies were determined and R&D plan was drafted.

Details will be presented at Top Fuel 2016.

Extracts from determined long-term R&D strategy

- Modified stainless steel including ODS-FeCrAl
 - Select advanced alloy with highest performance, developed based on ODS steel, and aim at achieving TRL-4
 - According to R&D plan, obtain basic data and detailed analysis for fuel design, and proceed technology development of fabrication and quality management and consider standards and criteria
 - Attempt to accumulate data by material irradiation test and survey showstopper. Accumulate data for designing prototype fuel if decisive showstopper cannot be found
- SiC/SiC composite
 - Consider solution of showstopper and aim at achieving TRL-3
 - Prioritize necessary R&D to clarify the upper limit of final target, including R&D for fuel design, important element technology for fabrication, and quantitative evaluation of effect of implementation for various accident conditions
 - Make a judgement about existence of showstopper from results of short and mid-term tests and analyses (Hold point). If showstopper is not found, continue R&D to accumulate data for designing prototype fuel.

Extracts from determined long-term R&D strategy

- TRISO fuel
 - Reasonable to proceed fundamental R&D as optional technology of SiC/SiC composite. Steady R&D of basic level is recommended for data for fuel design, fabrication and quality management, standards and criteria.
- ATCR
 - Reasonable to proceed fundamental R&D as promising optional technology of ODS-FeCrAl and SiC/SiC composite.
 - To taking advantage of the implementation effects especially on reduction of re-criticality risk and earlier implement into existing LWR for improvement of safety, should aim at achieving TRL-3.

To establish technical basis for practical use of “advanced fuel components” including accident-tolerant fuel components in existing LWRs,

- Investigations were made about the status of research and development.
- Preliminary evaluation of influence of implementation on core and plant behavior, safety evaluation method such as SA analysis, fuel design and behavior, etc. by codes including fuel design codes for industrial use. As a result, analytical subjects and data gaps were indicated.
- Specific definition of TRL was made and development for four candidate materials assuming uses in PWRs and BWRs was evaluated using the TRL, in terms of reactor core design, thermo-hydraulic characteristics, safety evaluation, standards and criteria, storage, transport, reprocessing, waste disposal and treatment in addition to fuel design and fabrication technologies.
- Original attribute guide for the development and performance regimes was created and assessment levels “Color code” depending on materials were refined.
- Based on the above investigations, short-term and long-term R&D plans were made for the candidate ATF components.

According to the drafted plan, we conduct R&D including fundamental examinations, analytical studies on implementation effects, computer code modification and material irradiations at a research reactor.