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Research Activities on Ageing Technical Evaluation in Japan

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Background of Research Activities on Ageing Management

Circumstances

- It has been passed for about 40 years since start of the first commercial nuclear power plant. Many efforts have been continued to improve the nuclear power facilities and developed the related codes and standards based on the lessons and learned of incidents.
- Under these circumstances, Light Water Reactor field was identified as one of the prioritized research areas, and among LWR field, material degradation and ageing management technology were pointed out as one of the important research activities in the Nuclear Safety Committee's report in July 2005.

Priority Research Areas

1. Regulatory System
2. **Light Water Reactor**
3. Fuel Cycle Facility
4. Rad-waste and Decommissioning
5. Advanced Reactor
6. Radiation Effects
7. Nuclear Emergency Preparedness

Research Activities

- Safety Evaluation Technology
  - **2) Material Degradation and Ageing Management Technology**
  - 3) Seismic Safety Technology

Ref: Nuclear Safety Committee, Special Committee on Nuclear Safety Research Report on "Prioritized Plan for Nuclear Safety Research", July 2005.

Research on Material Degradation and Aging Management Technology of Nuclear Power Plants

Material Degradation and Ageing Management Technology

Exact **Safety Regulation** for Nuclear Power Plants

Promotion of **Aging Management Technology**

Knowledge on **Material Degradation**

・To maintain integrity and performance of structural materials for major structures and components during operation period.

・ LWR: more than 30 years operation experiences

・ Various kinds of incidents caused by the materials

Understanding of phenomena and root causes

Technology development and verification for prediction and countermeasures

Integrity evaluation technology

Ref: Nuclear Safety Committee, Special Committee on Nuclear Safety Research Report on “Prioritized Plan for Nuclear Safety Research”, July 2005.

Research on Material Degradation and Aging Management Technology of Ageing Nuclear Power Plants

Research Needs from Regulatory Authorities

Ageing Technical Evaluation and Ageing Management

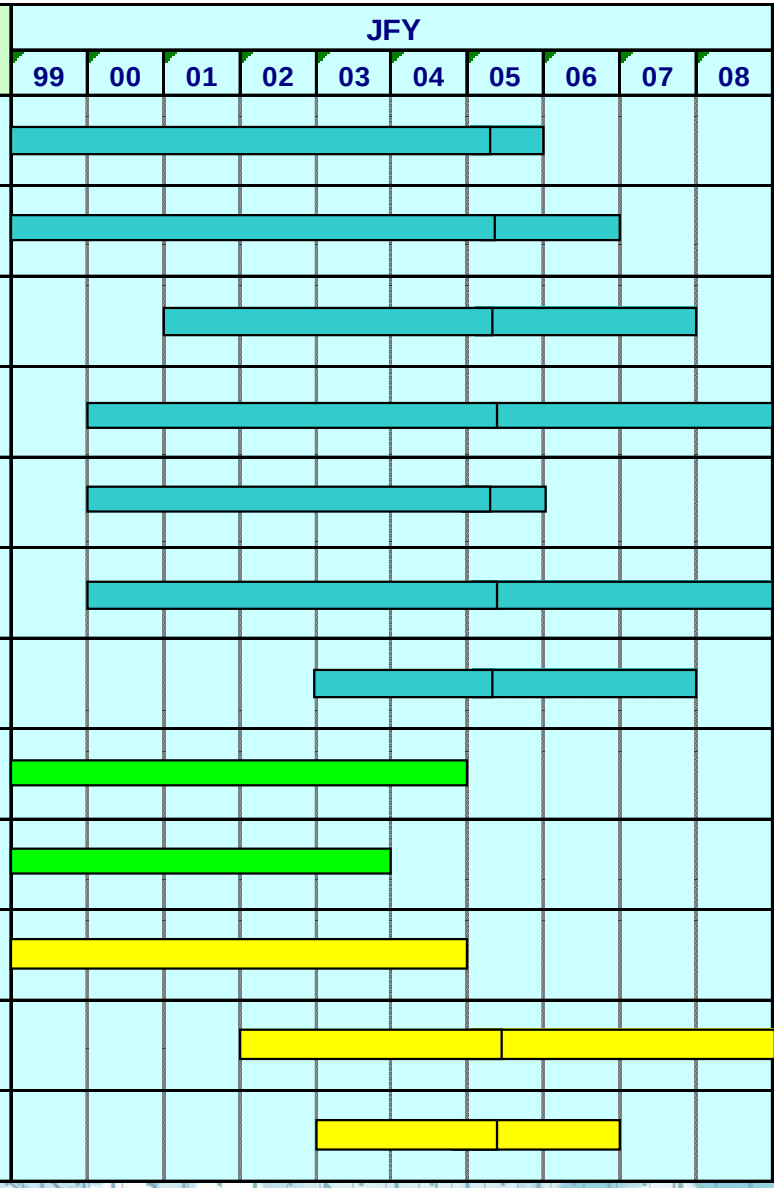
- **Technology Category**
  - **Inspection and Monitoring**
  - **Ageing Evaluation**
  - **Preventive Maintenance and Repair**
- **Ageing Phenomena and Technical Issues**
  - Neutron irradiation embrittlement,
  - Environmental fatigue
  - Thermal embrittlement
  - Non-destructive diagnosis of cables
  - Repair and replacement
  - Material improvement etc.

Fitness-for-Service Assessment

- **Material Issues** of recent incidents of major components
  - Low carbon stainless steels
  - Nickel base alloy weld joints
- **Technical Area**
  - Understanding of ageing phenomena and root causes
  - Technology development and verification for prediction methods and countermeasures
- **Structural Integrity Evaluation**
  - **Evaluation of SCC**
  - Detection and Sizing of SCC

Research Projects related Material Degradation and Ageing Management Technology Funded by NISA

Category	Major Projects	Priods
Ageing Evaluation	Nuclear Power Plant Integrated Management Technology (PLIM)	1996-2005
	Environmental Fatigue Tests of NPP Materials for Reliability Verification (EFT)	1994-2006
	Integrity Assessment of Flawed Components with Structural Discontinuity (IAF)	2001-2007
	Assessment of Cable Aging for Nuclear Power Plant (ACA)	2002-2008
Evaluation of SCC	Evaluation Methodology of Crack Growth Rate for Ni-based Alloys (NISCC)	2000-2005
	Evaluation of Irradiation Assisted Stress Corrosion Cracking (IASCC)	2000-2008
	Intergranular Stress Corrosion Cracking of Nuclear Grade Stainless Steel (IGSCC)	2003-2007
Maintenance & Repair	Repair Welding Technology of Irradiated Materials (WIM)	1997-2004
	Nuclear Power Plant Material Improvement Technology (PMT)	1996-2003
Inspection and Monitoring	Development of Standards for Formation of Upgraded Inspection System on NPP (SGF)	1992-2004
	Nondestructive Inspection Technologies on Ni-based Alloy Welded Joint (NNW)	2002-2008
	Nondestructive Inspection Technologies for Core Shroud Integrity Assessment (NSA)	2003-2006



Major Aging Phenomena of Major Components and Structures (PWR)

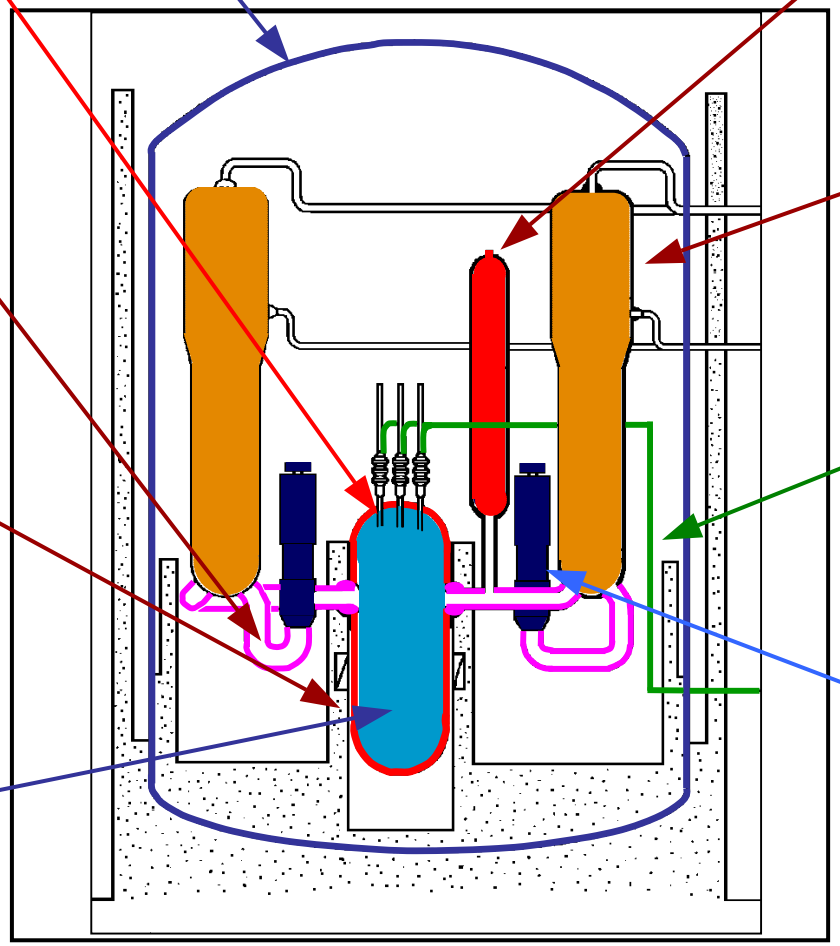
Reactor Vessel
Irradiation Embrittlement, Fatigue, SCC

Main Coolant Piping
Fatigue, Thermal Embrittlement

Concrete Structures
Strength Degradation and Shielding Performance degradation

Reactor Internals
Irradiation Assisted SCC, Irradiation Embrittlement

Primary Containment Vessel
General Corrosion



Pressurizer
Fatigue, SCC

Steam Generator
Fatigue, Corrosion, SCC

Cable
Degradation of Insulation

Reactor Coolant Pump
Thermal Aging, Fatigue

SCC: Stress Corrosion Cracking

Research Related Ageing Evaluation

- **Irradiation Embrittlement**

  [Nuclear Power Plant Integrated Management Technology (PLIM)]

  -Integrity Evaluation of Reactor Vessel with Low Upper Shelf Energy (USE)

- **Fatigue**

  [Environmental Fatigue Test of Nuclear Power Plant Materials for Reliability Verification (EFT)]

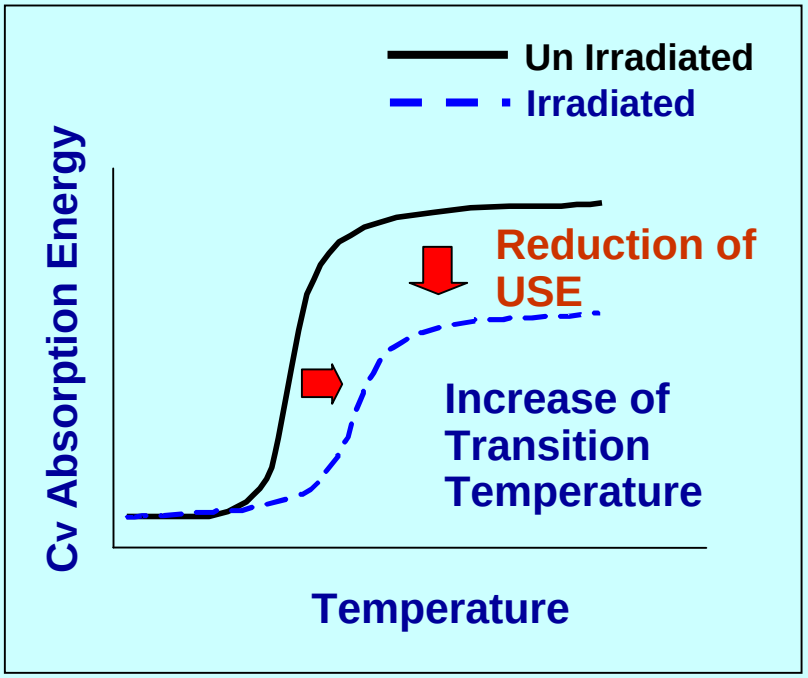
- **Stress Corrosion Cracking**

  [Evaluation Methodology of Crack Growth Rate for Ni-based Alloys (NISCC)]

Evaluation of Irradiation Embrittlement
Integrity Evaluation of Reactor Vessel with Low Upper Shelf Energy (USE) (1/2)

Background

- Neutron irradiation affect the toughness of RPV steels in both transition temperature region and upper shelf region.



- Prediction models of increase in transition temperature for transition region have been already formulated.
- Applied to evaluation of integrity of PTS.
- Charpy Upper Shelf Energy (USE) regulated to be > 68J during service period
- In codes and standards, no description how to evaluate the integrity of RPV in the case of low USE below 68J.

Objectives

To establish the evaluation method for RPV steels with low USE below 68J.

- Establishing the prediction equation of USE value
- Establishing the correlation equation between USE and J_{IC}

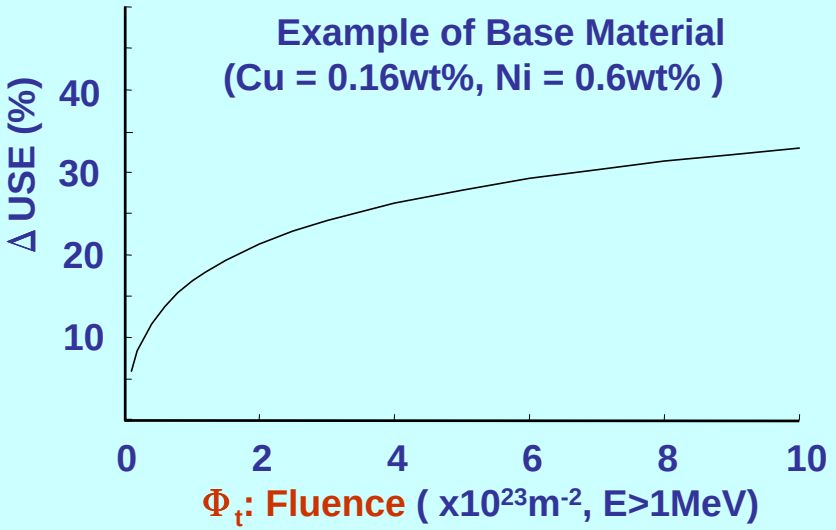
Evaluation of Irradiation Embrittlement
Integrity Evaluation of Reactor Vessel with Low Upper Shelf Energy (USE) (2/2)

Prediction Models for Base Metal (Example)

USE predicted = (1- ΔUSE / 100)

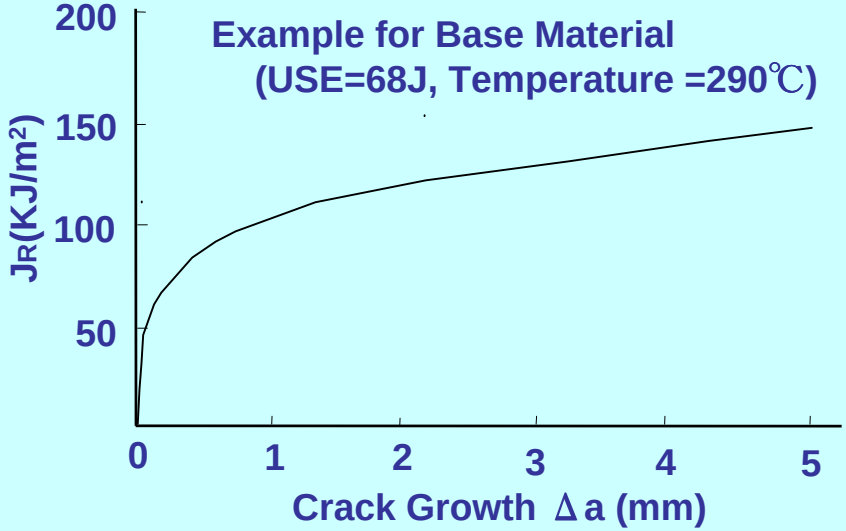
High fluence data (≦10^{24}n/m^2) and Japanese surveillance data
Based statistical model established in 2002

$$\Delta USE(\%) = -0.95 + (5.23 + 9.36 \times (0.5 + 0.5\tanh((Cu - 0.087)/0.034)) - (1 + 0.59 \times Ni)) \times \Phi t^{0.349 - 0.068\log(\Phi t)}$$



Correlation equation between USE value and JIC value

$$J_R(KJ/m^2) = 1.05 \times 0.82 \times C_1(\Delta a)^{C2}$$
$$C_1 = \exp(0.147 + 2.64\log(USE) - 0.00087T)$$
$$C_2 = -0.55 + 0.38\log(C_1)$$



Evaluation of Fatigue

Environmental Fatigue Tests of Nuclear Power Plant Materials for Reliability Verification (EFT)

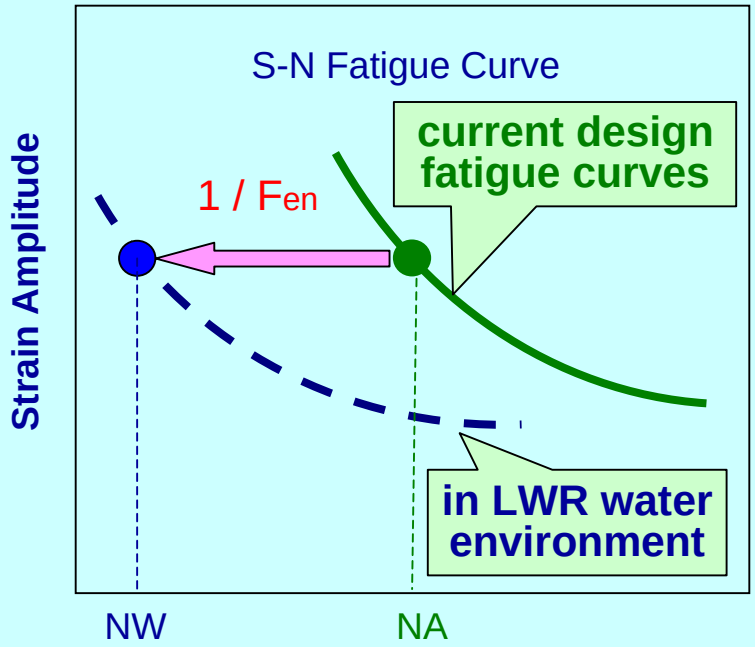
Background

- In nuclear power plant component design, fatigue assessment was conventionally conducted according to the Technical Standard for Construction of Nuclear Power Plant Components (MITI Notification No. 501, 1980), which was issued based on ASME B&PV Code Sec. III.
- Some papers on remarkable reduction in fatigue life of structural materials in LWR coolant have been reported by Japan, USA and others.
- In order to characterize the factors such as strain rate of loading, temperature, dissolved oxygen content etc, and evaluate the environmental fatigue life, EFT Project was started under the auspices of Ministry of Economy, Trade and Industry (METI) since 1994.

Environmental Fatigue Tests of Nuclear Power Plant Materials for Reliability Verification (EFT)

Objectives

- To characterize the factors such as
  - Temperature (T),
  - Strain rate of loading ($\dot{\varepsilon}$),
  - Dissolved oxygen content (DO)
  - Sulfur content in steel (S)
- To evaluate the effects on fatigue life quantitatively by conducting the fatigue tests under the simulated LWR water environment parametrically.
- To develop and verify an environmental fatigue evaluation Method to be used in assessing the environmental fatigue life of LWR component materials.



Fen = NA / NW
NA: Fatigue Life in Air
NW: Fatigue Life in Water

Environmental Fatigue Correction Factor (Fen) in indicates the degree of reducing the fatigue life in reactor water environment.

Environmental Fatigue Correction Factor F_{en} (1/2)

[Carbon and Low Alloy Steels]

$$F_{en} = \exp\left[-\left(0.199 \times T^* \times O^* + 0.112\right) \times S^* \times \dot{\varepsilon}^*\right]$$

where,

$\dot{\varepsilon}^* = 0$ ($\dot{\varepsilon} > 1.0\%/s$)

$\dot{\varepsilon}^* = \ln(\dot{\varepsilon})$, ($0.0004\%/s \leq \dot{\varepsilon} \leq 1.0\%/s$)

$\dot{\varepsilon}^* = \ln(0.0004)$, ($\dot{\varepsilon} < 0.0004\%/s$)

$T^* = 0.00531 \times T - 0.7396$ ($T \geq 180°C$)

$T^* = 0.216$ ($T < 180°C$)

$O^* = 0$ ($DO < 0.03$ ppm)

$O^* = \ln(DO/0.03)$ (0.03 ppm $\leq DO \leq 0.5$ ppm)

$O^* = \ln(0.5/0.03)$ ($DO > 0.5$ ppm)

$S^* = 17.23 \times S + 0.777$

$F_{en} = 1.0$ ($\varepsilon_a \leq 0.042\%$)

Evaluation of Fatigue

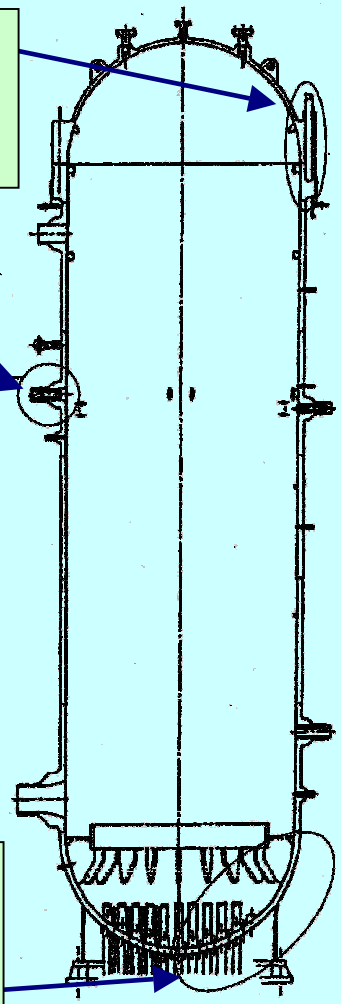
Environmental Fatigue Tests of Nuclear Power Plant Materials for Reliability Verification (EFT)

Examples of EPs

Main Flange and Flange (Low Alloy Steel)

Feedwater Nozzle (Low Alloy Steel)

Lower Head and Support Skirt (Low Alloy Steel)



Flow of Evaluation

Evaluation Points (EPs)

Stress

Transients

Postulated numbers based on actual transients (Ex. at 60 yeas)

Fatigue Design Curve

METI Notification No.501 (ASME Code Sec. III)

MITI guideline for Environmental Fatigue Initiation Life Reduction in LWR Environment

Fatigue Evaluation

UF < 1.0

Counter-measures

Integrity Evaluation

Evaluation of Stress Corrosion Cracking
Evaluation Technology for SCC Growth of Nickel Based Alloy (NiSCC)

Background

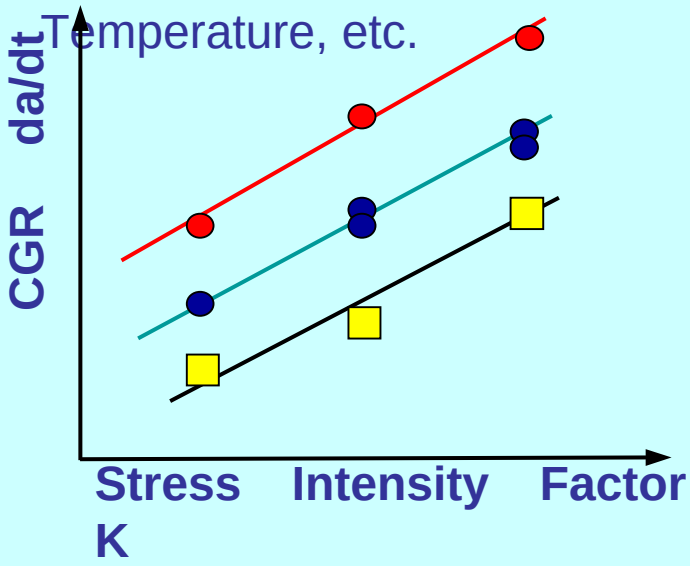
- SCC of Ni based alloys in pressure boundary components of PWRs and BWRs
- Evaluation of crack growth due to SCC
- Structural integrity assessment
- Develop the CGR evaluation method for base and weld metals of Ni base alloys has been recognized.

Objectives

- Obtain the sufficient data of CGR in Ni-based alloys under BWR and PWR environments for base metals and weld ones.
- Prepare “CGR vs K“ curves for integrity evaluation of nuclear plants.

CGR vs K curve

Parameter : Materials, Water chemistry, Temperature, etc.

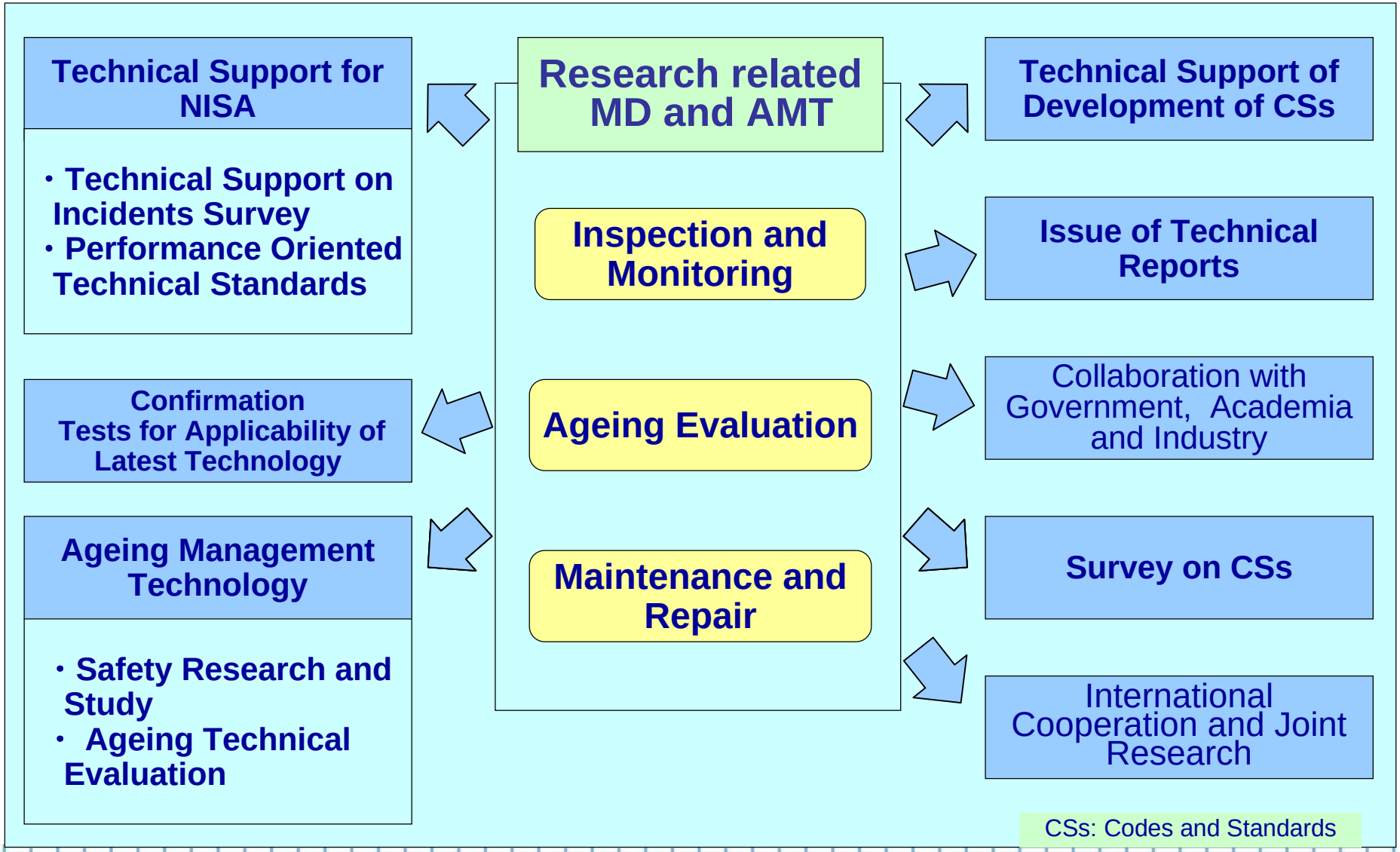


For Fitness-for-Service Assessment

Codes and Standards Established from Results of Research Projects

	Items (Components)	Projects (Period in JFY)	Code & Standard Guideline	Remarks
1	Environmental Fatigue Evaluation (BWR/PWR Pressure Boundary, Core Internals)	EFT (1994-2006)	- Environmental Fatigue Evaluation Guideline (ANRE, 2000 Sep.)	- Carbon Steels, Low Alloy Steels - Stainless Steels
2	RPV Embrittlement Evaluation - Prediction of shift of Reference Temperature - PTS Integrity Evaluation (PWR)	PTS (1983-1991)	- JEAC4201-1991（JEA） - JEAC4206 -1991 Appendix 3 (JEA)	- Embrittlement Prediction - PTS Criteria based on deterministic Fracture Mechanics
3	Detectability and Sizing of Flaw in Components and Core Internals by using Ultrasonic Testing	SGF/UTS (1995-2004)	- JEAC4207-2004 （JEA）	- Applied to Flaw Detectability and Sizing Accuracy by UT
4	Integrity Evaluation of Reactor Vessel with Low Upper Shelf Energy (USE)	PLIM (1999-2005)	- JEAC4201-2004 Appendix 1 (JEA) - JEAC4206-2004 Appendix 7 (JEA)	- USE Reduction Prediction Equation and Correlation Equation of USE-JR - Elastic-Plastic Fracture Toughness Evaluation of RV with Low USE
5	Fatigue Crack Growth Prediction and Evaluation (BWR Carbon Steel Piping)	SAF (1991-2000)	- Under review at JSME	- Used for revision of Fatigue Crack Growth Rate Evaluation
6	Applicability of Preventive and Repair Technology for Core Internals	PMT (1996-2003) WIM (1997-2004)	- PMT's Output: under review at JASME from 2004JFY. - WIM's Output: to be reviewed from 2005JFY .	- Applied to technical Data for Judgment of the Applicability of the Preventive and Repair Technology to Irradiated Materials with Helium.

Further Activities on Material Degradation (MD) and Ageing Management Technology (AMT)



Summary

- Regarding ageing management in Japan, researches on material degradation and ageing management technology were identified as one of prioritized research activities for Light Water Reactor Area.
- And also, it is important to conduct researches in the fields of inspection and monitoring, ageing evaluation, and preventive maintenance and repair technology.
- Japan Nuclear Energy Safety Organization (JNES) has been conducting research activities related ageing management and material degradation of nuclear power plants, in collaboration with NISA of the nuclear safety ensuring in Japan.
- JNES continues to provide NISA with technical basis for review of aging technical evaluation conducted by licensees and to support establishment of code and standards in order to make sure that the methodology and criteria of the evaluation and review process will be clarified.