Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 16-18, 2018

PIRT Analysis for Spent Fuel Rod Integrity Evaluation under Transportation

Kang-Hee Lee [a*], Heung-Soek Kang [a], Jae-Yong Kim [a], Yong-Sik Yang, Chang-Hwan Shin[a]
[a]*Nuclear Fuel Safety Research Division, Korea Atomic Energy Research Institute*
[*]*Corresponding author: leekh@kaeri.re.kr*

1. Introduction

Issue on integrity and retrievability of the spent fuel for the long-term dry storage has been raised recent years as the decision of national policy on spent fuel disposal has been delayed and the storage capacity reaches to the capacity limit in the domestic nuclear power stations. KAERI nuclear fuel safety research division do the government-funded research project on understanding degraded mechanism of the spent fuel before/during/after the dry storage and developing a prediction model for structural integrity, mechanical behavior and property variation with experimental validation supported by simulated fuel fabrication technology.

Under this stance, study on the structural failure of the long-term degraded spent fuel rod from repeated impact loading is worthwhile because the spent fuel degradation is concentrated mostly on the material aspect to brittle phase by the corrosion, hydrogen pickup and oxidation, and from aging [1]. Impact and repeated loading during the transportation can lead to fatal failure to the spent fuel rod supported by the gap spring supports after the long-term dry storage. In this study, PIRT analysis for the experimental study on the failure of span-wise simulated fuel under transportation was performed to design a test matrix related to the influential factors, their test range and test conditions, priority of test order.

2. PIRT analysis

PIRT refers to the phenomena identification and ranking table. PIRT targets for understanding system response to be studied, making it necessary to propose an experimental program, formulate a computer program, or describe another research activity [2, 3]. Group of engineers and scientist use their expertise, experience and judgement to list and rank associated phenomena, components and processes which could play a role in the system response or behavior, according to the their relative importance as H(igh), M(edium), and L(ow). Phenomena, components and processes understanding also are ranked according to the K(nown), P(artially known) and U(nknown). Phenomena, components and processes with ranks of "H" and "U" are need to be studied further(often with supporting experiments) before verified computer models can be formulated for the system prediction. Fig. 1 shows a typical PIRT process of developing a method to verify the adequacy of best estimate codes in the licensing of a nuclear power plant (NPP).

The first step of PIRT analysis is to define a problem and then decide objectives and scope of interest. What are the influential factors of high importance among the factors that affect the failure of degraded SNF rod under transportation and dynamic loadings event.

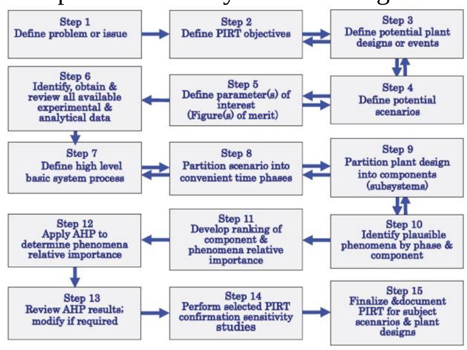

Figure 1. Illustration of typical application on the PIRT process.

Fig.1 Typical PIRT process of developing a method to verify the adequacy of best estimate codes in the licensing of a nuclear power plant (NPP).

Which factors are not understood sufficiently; and how much will the factor affect the structural failure of SNF rod under transportation. Our problem is to perform experimental study to understand failure behavior of simulated SNF rod under dynamic loading events. And our PIRT objective is to identify important influential factors that affect the failure behavior of SNF rod. Furthermore, extracting important research themes necessary for improving prediction capability of failure for each influential factor, and developing the ranking of importance can be added to our objectives.

Next step is to narrow range of the system or plant of interest. Instead, physical domain of the our experiment can be narrow into pellet-pellet interface region within the span-wise fuel rod or section specimen supported by grid springs, under impact to rigid plate and excitation by the shaker. All these are summarized as followings: material aspects including H2 pickup contents, quantity of oxidation and crud, the size of micro pre-defect, the tube size of 300~800mm tubular with pellet, supporting grids system with a finite clearance, excitation setup with control system, magnitude of impact and finally detection method of structural failure.

Table 1 shows the potential phenomenon, occurring in the system, which is a failure experiment of simulated spent fuel rod under the condition of transportation. Before defining parameters of interest (or figures of merits), we need to define evaluation criteria used to judge the relative importance of events or phenomena in the system of interest. Those can be physical equivalences of pre-structural defects and simulated fuel specimen, excitation condition to real transportation loadings and external impact and accuracy to detect the start of failure initiation. Thus, potential scenario and influential factors can be classified into 5 groups: A) preparation of the rod specimen with pre-defect to be measured or fabricated, B) excitation of the expected load and control, C) support gap and design features of support springs, D) magnitude and number of repeat of the impact, E) failure criteria and instrumentation for the failure detect. The pre-structural defect as test parameters suggested the fact that the every structural failure start from the structural defects because the most spent fuel has many defects in/outside of the claddings surfaces from the reactor use and long-term storage environment.

Table. 1. Phenomena occurring in the failure experiment under the condition of transportation and earthquake.

Phenomena during the experiment	Influential factors
A. Specimen preparation	1) H2 contents, 2) pre-defect, 3) surrogate pellets
B. Delivering excitation force(bending moment coupled with impact)	1) amplitude, 2) waveform, 3) frequency
C. Support grid system	1) spring K, 2) spring shape, 3) gap
D. Mid grid impact to rigid plate	1) impact mag. 2) number of impact, 3)shape of punch or rigid body
E. Detecting fatigue failure at the region of interest	1) instrumentations for response, 2) synthesis methods 3) failure criteria

The step to define plausible phenomena by components is to decide which are likely to be occurred and process in failure evaluation experiment on the basis of previous steps. We have to identify major influential factors to affect subsystems and how those factors would affect each figure of merits, i.e., the criteria based on importance and knowledge level related to those factors. We did make comprehensive describing tables with respect to each influential factors, but we did not show here in detail. Interested readers can refer to [4]. Finally, we made a priority table as shown in Fig. 2. Ranking criteria were based on the importance and knowledge level of the each influential factors. The table will help to identify important influential factors that affect the dynamic failure and extract important research subjects necessary for better simulation of the phenomena and better prediction of life of spent fuel during/under transportation. It is important to evaluate how the current knowledge was enough, and then we decided to rank the knowledge levels on the influential factors in terms of the amount of knowledge. But final test matrix needs further adjustment. For example, pre-structural defect was removed in the test matrix because it is very hard to verify physical equivalency to failure occurring in the real fuel rod.

H(igh)	P1 A(2): Pre-defect B(2): No. of cycle E(3): failure criteria D(1): No. of impact	P2 A(1) : H2 content B(1): Amplitude C(3): Support gap	P6 E(1):Instrumentation
M(edium)	P2 A(3): Surrogate Pellet B(3): Frequency E(2): synthesis method	P3 A(4): Residual stress D(2): Mag. of impact	P6 C(1):Spring K
L(ow)	P4 B(4) Wave form	P5 D(3) Shape of punch	P6 C(2) Spring shape
	U(nknown)	P(artially known)	K(nown)

A: Specimen, B:Excitation, C:Support, D:Impact, E: Detection,
P(riority) with Color :1(R), 2(B), 3(P), 4(G), 5(O), 6(Bk).

Fig. 2 the final PIRT analysis result table for SNF rod failure evaluation under transportation.

3. Conclusions

In this study, PIRT analysis for the span-wise simulated fuel rod integrity evaluation experiment to repeated bending and impact loadings was performed to design a test matrix (influential factors, their test range and conditions, priority of test order). Through a PIRT analysis, test parameters were grouped into 5 categories and test ranges and priority was determined based on the importance and understanding for the each influential parameter groups. Test matrix has a descending order from the limit test case to minimize the number of unnecessary test operation. The results of this study can be used for the evaluation of integrity and retrievability of the spent fuel under transportation. To extend the applicability of this study, more efforts are need for additional testing and analysis simulation.

ACKNOWLEDGMENT

This work was funded by the Radioactive Waste Management Technology Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea. (No. 2014171020166A)

REFERENCES

[1] John H. Kessler, 2017, Review of used nuclear fuel storage in the US and Korea-Options for Korea Long-term spent nuclear fuel management strategy, KAERI/CM-2410/2017.

[2] NUREG/CR-6744, LANL, Phenomenon Identification and Ranking Tables (PIRTs) for Loss-of-Coolant Accidents in Pressurized and Boiling Water Reactors Containing High Burnup Fuel,

[3] Takayuki Aoki et al, 2014, Study of a methodology of identifying important research problems by the PIRT process, journal of Nuclear Science and Technology, Vol. 51, No. 6, p. 832-844.

[4] Kang-Hee Lee, et al, 2018, Spent fuel structural integrity evaluation test plan for repeated bending and impact loading: test matrix, KAERI/TR-7222/2018.