DEVELOPMENT OF INFORMATION SYSTEM FOR POST-EARTHQUAKE PLANT EVALUATION AND EVACUATION SUPPORT

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ABSTRACT :

The Japan Nuclear Energy Safety Organization (JNES) evaluated the seismic risk for representative plants, using seismic PSA technology, and demonstrated that the radiation risk of the public depends largely on the possibility of evacuation of residents in the vicinity of nuclear installation. JNES is now developing the information system PEES (the information system for post-earthquake Plant Evaluation and Evacuation Support). PEES has capabilities to estimate both post-earthquake plant state and estimate of offsite damages, (e.g. possible damages of bridges and roads in the vicinity of installations) and to identify evacuation routes considering release behavior of radioactive materials (FP), location of shelters and arrangements of vehicles for evacuation, in order to comprehend the risk of resident evacuation. The results of the simulation can be used for local emergency preparedness plans and transportation plans. In emergency, a similar accident scenario is searched from the results of simulations performed in normal state. After that, successive reports are issued by revising the first report using actual data from the site.

KEYWORDS: seismic PSA, nuclear emergency, RARMIS, spatial temporal information system

1. INTRODUCTION

JNES evaluated the seismic risk for representative nuclear power plants (core damage frequency, containment damage frequency, and exposure of the public in the vicinity), using seismic PSA technology, and demonstrated that the radiation risk of the public depends largely on the possibility of evacuation of residents in the vicinity of nuclear installation [1]. Therefore, JNES is now developing the information system for evaluating post-earthquake plant integrity and communication with pertinent organizations. In FY 2004, the Seismic Emergency Information System developed by the former Japan Atomic Energy Research Institute was introduced. This system was developed on the basis of the concept of Risk-Adaptive Regional Management Information System (RARMIS) based on the Disaster Management Spatial Information System (DiMSIS) . After FY 2005 on, the system has been improved incorporating DiMSIS-Ex that has been sophisticated by the Earthquake Disaster Mitigation Research Center of the National Research Institute for Earth Science and Disaster Prevention (NIED) [2].

1.1. Background of concept and outline of Information processing Infrastructure

RARMIS is an ideal concept of field-oriented information system for local and regional authority that was born in the course of the emergency response activities immediately after the Great Hanshin-Awaji

Earthquake Disaster in 1995. It is a concept of information system to smoothly connect the functions for normal state and the functions for emergency time, focusing on the risk (possible future hazards and disasters), regional management (administrative services during normal time) and adaptiveness (response and coordination). The essential information infrastructure for functionality and economical efficiency include a. autonomous decentralized information linkage, b. Spatial-temporal information processing, c. open database structure, and d. spatial-temporal database. DiMSIS-Ex is currently utilized by many local and regional authorities, for instance, in the areas affected by the natural disaster (include of earthquake) [3].

1.2. Performance requirements and configuration of the Information System for Evaluating Post-earthquake Plant State and Evacuation of Residents due to large Earthquake

In accordance with the concept of RARMIS, the main performance requirements were specified as follows. (a) linkage between nuclear emergency and its initiating seismic disaster, (b) linkage with non-earthquake events (external events, e.g., tsunami, flooding and volcano, and random internal events), (c) collaboration between nuclear pertinent (related) organizations and local and regional authorities, (d) dual functions for normal state and emergency, (e) autonomous decentralized function (backup function), (f) actual operation system (around-the-clock system), (g) Spatial-temporal information processing function (automatic update of relevant data for office counter work of local and regional authority), (h) open database structure (linkage with existing relevant systems such as networks of FP detectors and plant systems), (i) both special and temporal seamless database (e.g. whole Japan special-temporal database) function, (j) consideration of different earthquake motion intensities in accident scenarios for nuclear emergency, since the accident scenario of nuclear emergency depends on the intensity of earthquake motion, (k) functions to estimate FP release behavior, damages of bridges and roads, and evacuation routes. The above requirements are considered in the configuration of the presented system as shown in Figure 1.

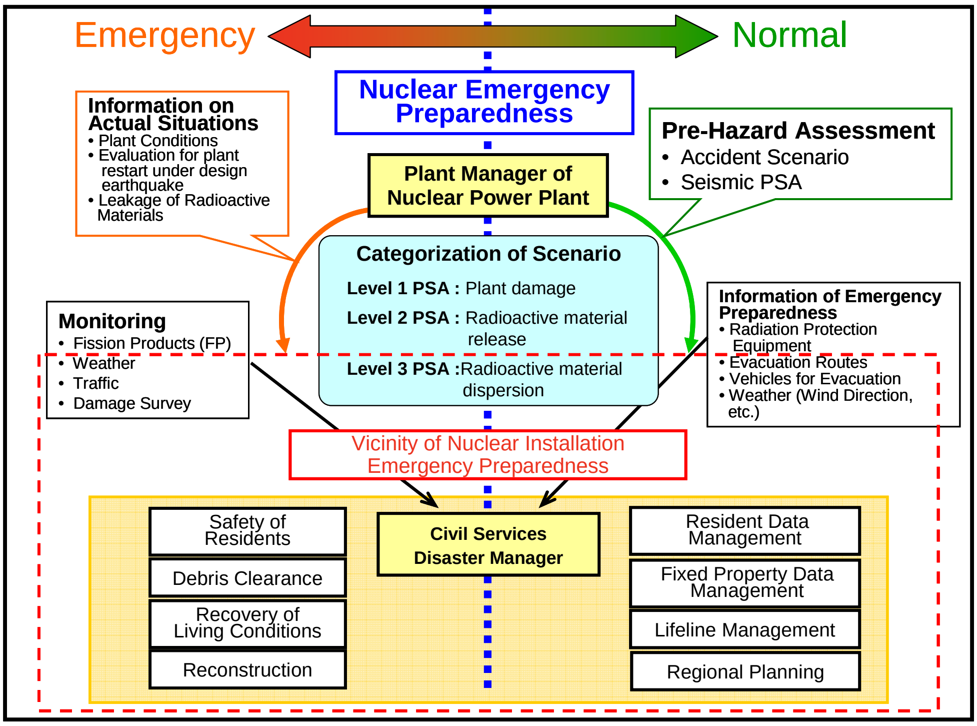


Figure 1. Conceptual diagram of PEES

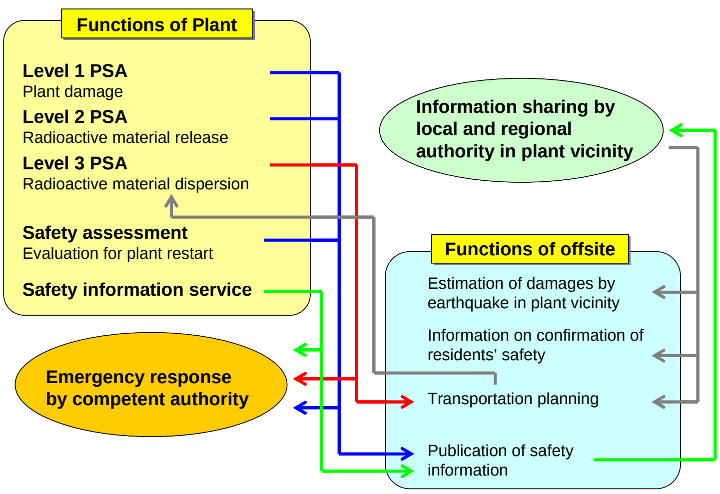
2. INFORMATION PROCESSING FOR LOCAL AND REGIONAL AUTHORITY

2.1. Information Processing contributes to risk reduction for the local and regional authority

Realistic risk assessment concerning resident-evacuation transportation requires transportation planning and identification of transportation routes that consider temporal movements and characteristics of individual resident. This system calculates the time required for resident transportation and identifies transportation routes, on the basis of: (1) traffic volume based on the result of confirmation of residents' safety after large earthquake, (2) traffic information on transportation routes (information on traffic-blocked areas due to dropped bridges or collapsed steep slopes, and traffic-banned areas due of dispersion or possible dispersion of radioactive materials), (3) information on transportation vehicles. In the preliminary evaluation of resident evacuation risks, it is necessary to evaluate the risks of public exposure which depends on the evacuating routes to the primary evacuation center and from there to the secondary evacuation center. Therefore, management of spatial-temporal movements of individual resident is required.

2.2. Construction of system by applying RARMIS concept to nuclear emergency

Plant and offsite modules of the system functions are shown in Figure 2. The affected area would be within several tens km from epicenter in the case of a near field earthquake in the vicinity of a site while broader area would be affected in the case of a large earthquake and communication facilities would be damaged. This system consists of two functions; one is information support for resident evacuation from non-affected areas and the other is the support for confirmation of residents' safety and collection of road traffic information by officials of local authorities (Figure 2). The risk assessment is conducted on the basis of information on evacuating residents and road traffic conditions collected through autonomous distributed cooperative process using laptop PCs with local government officers at the shelters. Such assessment work is carried out outside the affected areas where infrastructures such as information collection, communication and power supply are intact. Local and regional authority can use this system for daily works through utilizing its resident-related functions for the persons requiring aid and for the response to other natural disasters, by which basic data can be collected for the preliminary risk assessment. This system can be used as an emergency response support system which can surely function during emergency, by using it during normal time.



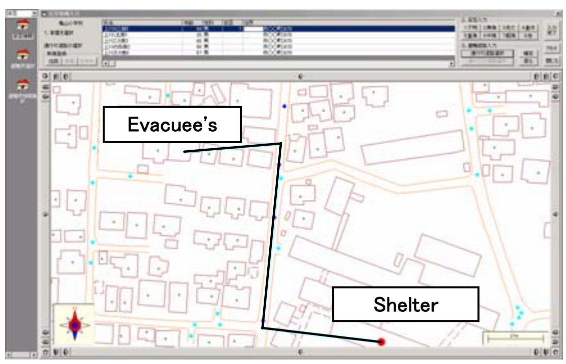


Figure 2. System functions and information flow

Figure 3. Functions to collect information on confirmation of residents' safety and traffic

In most of the current information systems of local authorities is client-server which is damaged, the function of the system is totally lost. By storing the basic data necessary for emergency response in each PC of autonomous decentralized information linkage used for daily works by individual personnel of local authorities and by exchanging differential information as necessary, effective processing of emergency information becomes available.

3. FUNCTION OF LOGISTICS ANALYSIS FOR EVACUATION OF RESIDENTS

3.1. Logistics analysis contributes to PSA

The public exposure risk depends largely on the possibility of evacuation of the residents in the vicinity of nuclear installation. Therefore, evaluation of the resident transportation root plan, vehicle arrangements, etc. is a necessary function of this system. In developing the system, resident evacuation support logistics was applied to nuclear emergency preparedness as a resident transportation planning function.

3.2. Outline of logistics analysis

Figure 4 shows the flow of the resident evacuation support logistics analysis. This flow consists of traffic weighting, route search, and transportation planning. Traffic weighting adopts highly versatile processing capable of network identification and two kinds of weighting in distribution region, etc. In process of route search, the shortest route is searched using Dijkstra method, taking account of traffic weighting. This process also has neighbor search capability around the destination such as evacuation center, in case of discrepancy between the location of evacuation center and network. Third Process develops a transportation plan, by combining the optimum solutions at every time points and using greedy algorithm (with function f) to obtain an approximately optimum solution as a whole. The following process is iterated for all vehicles until the evacuation of residents is completed.

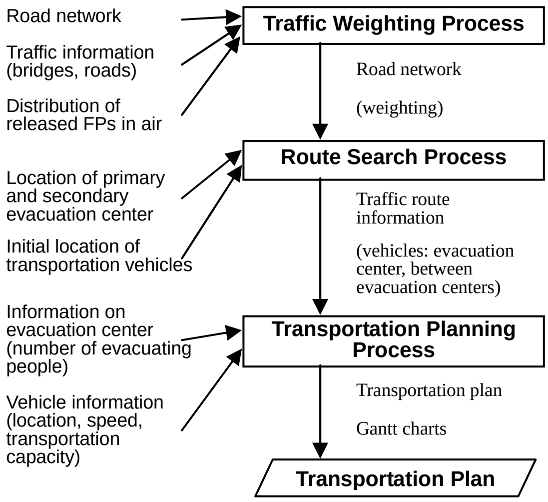


Figure 4. Flow of the evacuation support logistics analysis

$x = \min(f(r,a,b))$

x: transportation route　　r: traffic route

a: transportation capability　　b: number of evacuating people

4. EVALUATION FOR PLANT RESTART UNDER DESIGN EARTHQUAKE MOTION

Nuclear power plants in Japan are automatically scrammed when amplitude of observed seismic motion have reached close the set point level. The first action immediately after such scram is to inform the local people of safe shutdown of the plant. Status of the plant is then confirmed and results are explained to the local residents. After that judgment is made on the possibility of plant restart. Such judgment requires evaluation of the integrity of the buildings and components after earthquake. Therefore, domestic and foreign examples of plant restart and their procedures were surveyed and studies were made on the evaluation procedure, streamlining of evaluation and publication of evaluation results.

4.1. Survey of home and foreign information on plant restart after earthquake

- In the case of Japan

No information on post-earthquake plant restart was found by the survey. Then experiences in seismic integrity evaluation of the buildings and components of existing plans were considered in the evaluation procedure [4]. Evaluation for plant restart has been in the works for the one year in Kashiwazaki-Kariwa Power Plant that suffers from earthquake damage.

- In the case of overseas

Licensees have been preparing procedures and related documents in response to regulatory requirements concerning plant restart issued by United States NRC in 1997. No earthquake subject to the regulatory requirements has occurred up to now.

4.2. Routine preparation and emergency response for plant shutdown after earthquake

- Routine preparation

A procedure for plant integrity evaluation after earthquake scram is to be prepared and constantly revised to prepare for emergency.

-Emergency response

It is confirmed and communicated immediately after earthquake that the plant is successfully scrammed and whether or not accident conditions exist. After completing immediate post-earthquake actions, for further explanation about plant integrity, evaluation is conducted, in accordance with the above-mentioned procedure, on the plant integrity against experienced earthquake motion and possible future earthquake. The evaluation results are publicized and used for judgment on plant restart.

4.3. Outline of evaluation for plant restart

Plant integrity evaluation involves a huge number of components and requires many staffs who work jointly and efficiently. Therefore, a standard procedure for evaluation processes is prepared and analysis environment is improved to increase efficiency. In addition, a guideline is prepared to assist preparation of explanatory materials for public dissemination of the results. These are outlined below.

4.3.1. Evaluation procedure

(a) Selection of components: components having small safety margin against experienced earthquake motion are selected by simplified evaluation, considering seismic significance classification (class Ss) and yield strength. (b) Determination of input earthquake motion: earthquake motion is determined considering observed seismic waveform and the latest seismological knowledge. (c) Integrity evaluation criteria: allowable stress values of buildings and components are defined based on design information. (d) Seismic response analysis: stresses imposed on buildings and components are calculated using time history seismic response analysis, etc. with detailed analysis models. (e) Confirmation seismic safety: seismic safety is confirmed by examining stresses on buildings and components.

4.3.2. Streamlining of evaluation

(a) Automatic preparation of input data: an automatic input preparation function for piping system analysis code is developed to reduce work hours. (b) Analysis results summary sheet: analysis results summary sheet preparation function is developed for further enhancement of quality assurance for confirmation of analysis results.

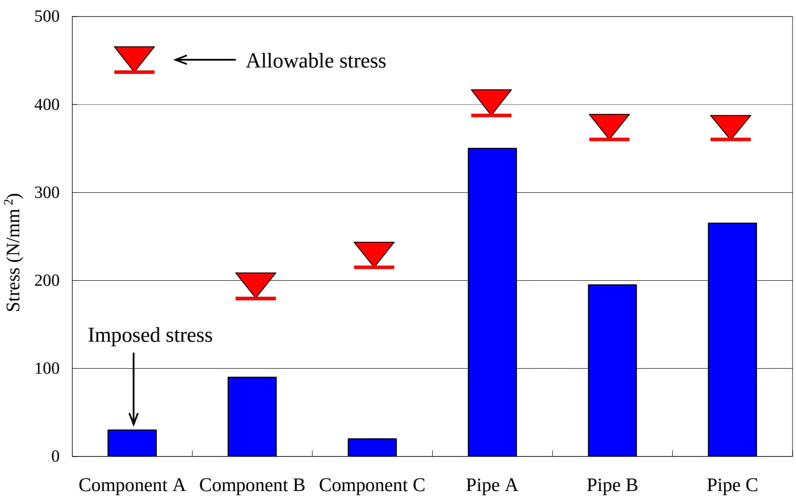


Figure 5. Example of component stress evaluation

An example for component stress comparison results is shown in the figure. (c) Implementation period and organization: standard evaluation work hours per plant and personnel organization are reviewed.

4.3.3. Publication of evaluation results

On evaluation results, (a) and (b) are conducted as appropriate. (a) Presentation to competent authorities: presentation is made on public occasions such as committees. (b) Explanation to local people and authorities: presentation is made at prefectural assembly, municipal assembly, town council, village council and local residents meeting, etc.

The many pieces of equipment that constitute a plant
→ Selecting the equipment, using the simple method
(The evaluation method is selected according to the seismic level.)

Assessment Target		Simple Method	Selection	Detailed Method
Building, structure	• Nuclear reactor building • Control building • Civil engineering structure, etc.	Nonlinear seismic response analysis		
Large-scale equipment	• Containment vessel • Reactor pressure vessel • Core internals	Building: Seismic response analysis, using the large-scale equipment coupling system model	Comparison between the designed response and response analysis results	Detailed stress evaluation
Equipment	• Equipment other than the above-mentioned large-scale equipment	• Floor response spectrum • Response analysis, using the earthquake intensity at the equipment installation location	•Seismic classification: High •Low tolerance •Unsatisfactory soundness	
Pipe work	• Pipe work			



Figure 6. Streamlining Post-Earthquake plant evaluation on plant restart

5. ESTIMATION OF DAMAGE IN THE VICNITY OF SITE AND IDENTIFICATION OF EVACUATION ROUTES UNDER THE EARTHQUAKE

JNES confirmed the fact that radiation exposure risk of local residents is largely depends on the possibilities of residents' evacuation and evacuation route, as a result of the level 3 seismic PSA (radiation exposure risk evaluation for residents around plants)[5]. On the basis of this fact, for comprehending radiation exposure risk during earthquake, JNES is now developing an information system for evaluating post-earthquake plant state, which can estimate damages of bridges and roads near the plant site, release and dispersion behaviors of fission products (FP), evacuation routes, etc. This system finds out resident evacuation routes under the earthquake.

5.1. Routine preparation and emergency use of scenarios to estimate facility damage, dose and evacuation routes around plant

5.1.1. Routine preparation

The data necessary for the estimation of damages and evacuation are prepared based on local authorities' data, including the data of road networks, steep slopes, bridges, evacuation centers, and arrangements of vehicles. A data-base for nuclear accident source term (types, release timing, release amount, etc. of radioactive materials) is developed for different plant types and intensities of earthquake motion, on the basis of the result of seismic

PSA. Simulations of damages and evacuation are carried out using these data to select several choices of evacuation route in advance. The results of the simulation can be used for local emergency preparedness plans and transportation plans.

5.1.2. Emergency use

A similar accident scenario is searched from the results of simulations performed in normal state, by inputting a plant type and actually observed data such as intensity of earthquake motion. The resultant scenario is used to prepare the first report on estimated damages around the plant and candidates for evacuation routes. After that, successive reports are issued by revising the first report using actual data from the site. Thus information is revised through two-way communications with the plant site.

5.2. Functions for estimating facility damage, dose and evacuation routes

The function to estimate damages of facilities, radiation dose and evacuation routes is composed of three elements; (1) estimation of damages of surrounding facilities, (2) dose calculation, (3) identification of evacuation routes. Element (1) includes estimation of seismic motions with a 250 m mesh, liquefaction of soil, damages of bridges and land slide, etc. to identify available routes. Element (2) calculates dose rate distribution around the plant using some assumptions and measurement data from FP monitoring posts. Element (3) identifies candidate evacuation routes considering available routes from (1) and access controlled areas based on dose rate distribution from (3). The logistic function (2) developed by the National Research Institute for Earth Science and Disaster Prevention is used for Element (3). The result of this estimation is revised taking account of information on actual resident evacuation routes.

5.3. Example of evacuation route estimation in normal state

Figure 7 shows an example of evaluation of evacuation routes for an assumed plant. Bluely shaded area represents the FP dispersion area. The shortest routes from the primary evacuation centers located within 10 km of the assumed nuclear plant to the secondary evacuation centers outside 10 km of the plant was found out considering information on access controlled area due to FP dispersion. This evaluation demonstrated the appropriateness of the above-mentioned functions to estimate facility damages, dose, and evacuation routes.

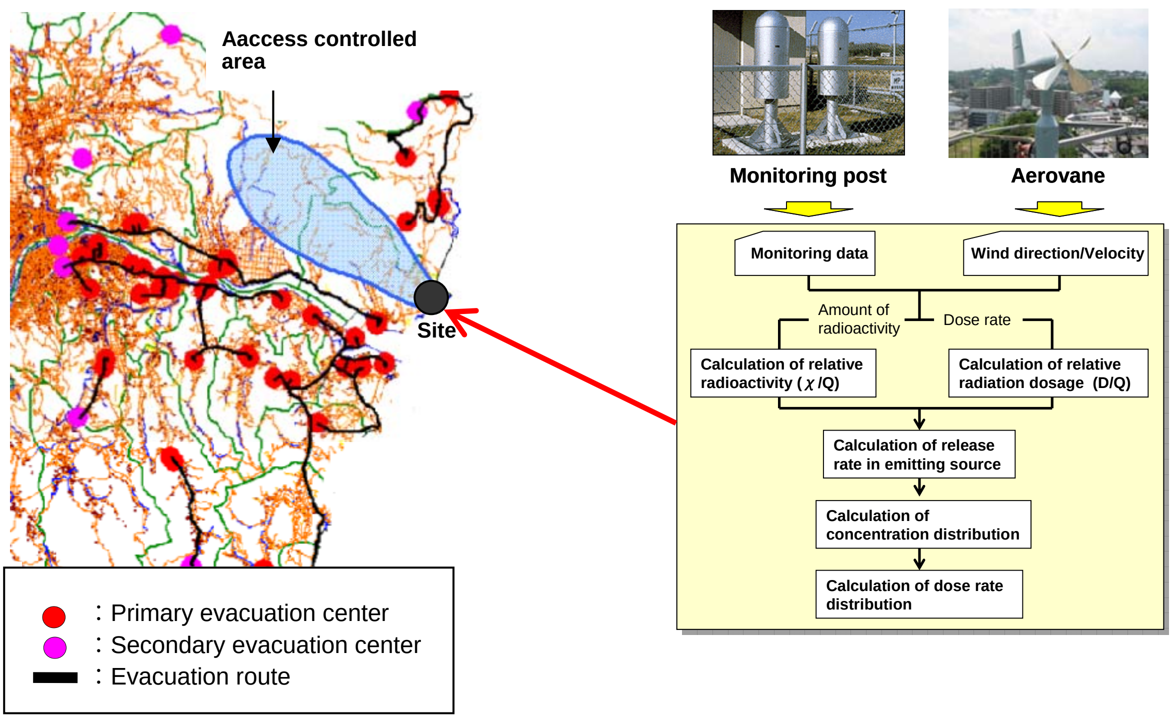


Figure 7. Example of evacuation route estimation based on estimation of FP emissions

6. CONCLUSION

JNES have developed prototype of PEES system based on evaluation of seismic risk using seismic PSA technology, and demonstrated that radiation risk of the public depends largely on the possibility of evacuation of residents in the vicinity of nuclear installation.
Development of PEES system that evaluated composite event of the radiological emergency and seismic hazard were conducted by the integration of nuclear seismic safety technology of JNES and earthquake disaster prevention based on information technology of NIED.
PEES would be scheduled to upgrade as follows;
- to apply the plant safety assessment procedure to the Kashiwazaki-Kariwa Power Plant and upgrade it
- to consider the measures to reduce seismic risk, while applying the PEES to the supposed area, conducting various evacuation-related simulations and considering the streamlining of evacuation
- to apply these results to the creation of accident scenarios in disaster prevention training and propagate them as useful information for establishing the nuclear disaster prevention plan.

In a three year plan beginning in FY2007, the IAEA, JNES and NIED jointly started the TiPEEZ (Protection of nuclear power plants against Tsunami and Post Earthquake considerations in the External Zone) project as the IAEA's extra budgetary project (EBP). The TiPEEZ system is an expanded international version of the PEES system. JNES will develop and help to operate the TiPEEZ for member states of IAEA, particularly for developing countries of nuclear disaster prevention in Asia in order to mitigate damage at nuclear installations and their surrounding areas caused by earthquake and tsunami disaster.

7. ACKNOWLEDGMENT

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