RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**425-8405**
SRP Section:	**04.02 – Fuel System Design**
Application Section:	**4.2**
Date of RAI Issue:	**03/01/2016**

Question No. 04.02-9

Title 10 of the Code of Federal Regulations, Part 50, Appendix A, Criterion 2, requires that SSCs important to safety are designed to withstand the effects of earthquakes without the loss of capability to perform their safety functions. The design bases for these SSCs shall reflect: (1) the severity of the historical reports, with sufficient margin to cover the limited accuracy, quantity, and time period for the accumulated data, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena, and (3) the importance of the safety functions to be performed. SRP Section 4.2 Appendix A (II)(2) provides review guidance regarding the review of methods used to analyze loads.

Technical Report APR1400-Z-M-NR-14010-P references CENPD-178-P as the methodology used to obtain the transient response. During an audit of the supporting references conducted during October 14-16, 2015, the staff noted that there are differences between the referenced methodology and the methodology actually used to calculate the seismic response for the PLUS7 fuel design and APR1400 plant design. One example of a deviation is the methodology used to determine a conservative natural frequency assumed in the analysis. This has caused the staff question the overall methodology used in the analysis.

A. Identify the complete methodology used to obtain the transient response highlighted in technical report APR1400-Z-M-NR-14010-P. Specifically, identify any deviations from the stated approved methodology and provide justification for the new methodology. If the methodology used differs from what is currently stated in the technical report, update the technical report as necessary.

B. Justify the use of 4.2 Hz as the BOL first mode frequency in the lateral vibration model under air and room temperature conditions instead of the value of 2.7 Hz used in the referenced methodology, which was based on a conservative

bounding of test data.

Response

The technical report APR1400-Z-M-NR-14010-P Rev.0 is revised to include test results and models of PLUS7 at BOL and EOL conditions, and analysis results at BOL condition.

A. There are deviations between the revised technical report APR1400-Z-M-NR-14010-P Rev.1 and CENPD-178-P Methodology as below:

   (a) The fuel assembly is excited near the center of the fuel assembly rather than at the lower end of the fuel assembly. The excitation position does not affect the modal characteristics of the fuel assembly. Also it is more efficient to excite the center of the fuel assembly rather than at the lower end of the fuel assembly to obtain the first modal characteristic of the fuel assembly, which is the primary interest mode than the other modes.

   (b) In CENPD-178-P methodology, the still water damping value is applied to the fuel assembly model for seismic and pipe rupture analysis. But the flowing damping value for the seismic and pipe rupture analysis will be used to take flowing water damping credit. The flowing water damping test have been performed to obtain the flowing water damping value of the PLUS7 fuel assembly.

   Through these reasons the deviations between seismic and pipe rupture analysis in technical report APR1400-Z-M-NR-14010-P Rev.1 and CENPD-178-P Methodology are acceptable.

B. The natural frequency at large deflection is used to develop fuel assembly model in revised technical report APR1400-Z-M-NR-14010-P Rev.1 instead of using the frequency at zero deflection.

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Report

Technical Report APR1400-Z-M-NR-14010-P Rev.0 is revised as the submitted Technical Report.

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Application Section:	**4.2**
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Question No. 04.02-10

Title 10 of the Code of Federal Regulations, Part 50, Appendix A, Criterion 2, requires that SSCs important to safety are designed to withstand the effects of earthquakes without the loss of capability to perform their safety functions. The design bases for these SSCs shall reflect: (1) the severity of the historical reports, with sufficient margin to cover the limited accuracy, quantity, and time period for the accumulated data, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena, and (3) the importance of the safety functions to be performed. SRP Section 4.2 Appendix A (II)(2) provides review guidance regarding the review of methods used to analyze loads.

Technical Report APR1400-Z-M-NR-14010-P references CENPD-178-P as the methodology used to obtain the transient response. During an audit of the supporting references conducted during October 14-16, 2015, the staff reviewed the referenced methodology and noted a section detailing the development of a bounding EOL vibrational model based on extensive testing of fuel that was available at the time. The staff did not see a detailed discussion which would demonstrate the applicability of the results from CENPD-178-P to the PLUS7 fuel design in APR1400 in terms of the vibrational model. This has caused the staff question the applicability of CENPD-178-P for this purpose.

Justify the applicability of the EOL vibrational model from CENPD-178-P to the PLUS7 fuel design for APR1400 with special consideration to the applicability of the test data used in CENPD-178-P to the PLUS7 fuel design.

Response

The technical report APR1400-Z-M-NR-14010-P Rev.0 is revised to include test results and models of PLUS7 at BOL and EOL conditions, and analysis results at BOL condition. PLUS7 fuel assembly vibration test at EOL condition was performed to develop EOL analysis model. The developed EOL model for PLUS7 fuel assembly is used for seismic analysis at EOL condition instead of using EOL vibration test results from CENPD-178-P.

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Report

Technical Report APR1400-Z-M-NR-14010-P Rev.0 is revised as the submitted Technical Report.

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SRP Section:	**04.02 – Fuel System Design**
Application Section:	**4.2**
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Question No. 04.02-11

Title 10 of the Code of Federal Regulations, Part 50, Appendix A, Criterion 2, requires that SSCs important to safety are designed to withstand the effects of earthquakes without the loss of capability to perform their safety functions. The design bases for these SSCs shall reflect: (1) the severity of the historical reports, with sufficient margin to cover the limited accuracy, quantity, and time period for the accumulated data, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena, and (3) the importance of the safety functions to be performed. SRP Section 4.2 Appendix A (II)(2) provides review guidance regarding the review of methods used to analyze loads.

During an audit of the supporting references for technical report APR1400-Z-M-NR-14010-P conducted during October 14-16, 2015, the staff reviewed the EOL natural frequency presented in the referenced topical report, CENPD-178 (specifically, in Figure 6-7). Assuming all other model parameters and load inputs remain the same, the limiting grid impact forces and guide tube bending stresses are expected to change with the choice of natural frequency. The proportional relationship between BOL and EOL natural frequencies is derived from this figure and is used to define the EOL natural frequency used in the APR1400 fuel seismic analysis.

A. Identify the bounding range of natural frequencies that encompass the anticipated deflection range of the EOL fuel assembly and justify the choice of representative natural frequency within that range.

B. How does impact force and guide tube stress vary throughout the bounding range of natural frequencies at EOL and how is analytical uncertainty addressed?

Response

The technical report APR1400-Z-M-NR-14010-P Rev.0 is revised to include test results and models of PLUS7 at BOL and EOL conditions, and analysis results at BOL condition. PLUS7 fuel assembly lateral vibration tests at EOL condition have been performed to develop fuel assembly model at EOL condition. Fuel assembly natural frequencies are determined from the forced vibration test at large deflection to cover the fuel assembly deflection range, and used for the fuel assembly models development for the seismic and pipe rupture analyses, instead of using the proportional relationship between BOL and EOL natural frequency from CENPD-178-P.

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Report

Technical Report APR1400-Z-M-NR-14010-P Rev.0 is revised as the submitted Technical Report.

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SRP Section:	**04.02 – Fuel System Design**
Application Section:	**4.2**
Date of RAI Issue:	**03/01/2016**

Question No. 04.02-12

Title 10 of the Code of Federal Regulations, Part 50, Appendix A, Criterion 2, requires that SSCs important to safety are designed to withstand the effects of earthquakes without the loss of capability to perform their safety functions. The design bases for these SSCs shall reflect: (1) the severity of the historical reports, with sufficient margin to cover the limited accuracy, quantity, and time period for the accumulated data, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena, and (3) the importance of the safety functions to be performed. SRP Section 4.2 Appendix A (III)(2) provides review guidance regarding the determination of strength for components other than grids.

During an audit of the supporting references for technical report APR1400-Z-M-NR-14010-P conducted during October 14-16, 2015, the staff reviewed the supporting EOL component stress analysis but no similar analysis was available for BOL component stress. Although EOL conditions are often limiting in terms of component stress analyses, BOL conditions must be investigated to ensure that limiting conditions are assumed in the component stress analysis.

Provide a BOL component stress analysis which justifies the assumption from technical report APR1400-Z-M-NR-14010 that EOL conditions are limiting.

Response

The technical report APR1400-Z-M-NR-14010-P Rev.0 is revised to include test results and models of PLUS7 at BOL and EOL conditions, and analysis results at BOL condition. Component stress analysis at the BOL condition was performed and the results are described in section 6.2.6 of the revised technical report, APR1400-Z-M-NR-14010-P Rev.1.

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Report

Technical Report APR1400-Z-M-NR-14010-P Rev.0 is revised as the submitted Technical Report.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

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Docket No. 52-046

RAI No.:	**425-8405**
SRP Section:	**04.02 – Fuel System Design**
Application Section:	**4.2**
Date of RAI Issue:	**03/01/2016**

Question No. 04.02-13

Title 10 of the Code of Federal Regulations, Part 50, Appendix A, Criterion 2, requires that SSCs important to safety are designed to withstand the effects of earthquakes without the loss of capability to perform their safety functions. The design bases for these SSCs shall reflect: (1) the severity of the historical reports, with sufficient margin to cover the limited accuracy, quantity, and time period for the accumulated data, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena, and (3) the importance of the safety functions to be performed. SRP Section 4.2 Appendix A (III)(1) provides review guidance regarding the determination of grid strength in order to meet Criterion 2.

Technical report APR1400-Z-M-NR-14010-P presents impact forces for APR1400 grids for in-water and in-air conditions. During an audit conducted during October 14-16, 2015, the staff reviewed supporting documentation, but noted that there was no justification presented for the damping values used.

Provide justification for the damping values used to support the structural analysis of the PLUS7 fuel assemblies for seismic and LOCA loading.

Response

The technical report APR1400-Z-M-NR-14010-P Rev.0 is revised to include test results and models of PLUS7 at BOL and EOL conditions, and analysis results at BOL condition. The BOL damping value at still water condition and the EOL damping value at flowing water condition are used for the seismic and pipe rupture analyses. The flowing water damping test for the PLUS7 fuel assembly has been performed to obtain the flowing water damping value. The damping value from the flowing water damping test will be used for the EOL analyses to have flowing water damping credit.

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Report

Technical Report APR1400-Z-M-NR-14010-P Rev.0 is revised as the submitted Technical Report.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

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RAI No.:	**425-8405**
SRP Section:	**04.02 – Fuel System Design**
Application Section:	**4.2**
Date of RAI Issue:	**03/01/2016**

Question No. 04.02-14

Title 10 of the Code of Federal Regulations, Part 50, Appendix A, Criterion 2, requires that SSCs important to safety are designed to withstand the effects of earthquakes without the loss of capability to perform their safety functions. The design bases for these SSCs shall reflect: (1) the severity of the historical reports, with sufficient margin to cover the limited accuracy, quantity, and time period for the accumulated data, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena, and (3) the importance of the safety functions to be performed. SRP Section 4.2 Appendix A (III)(1) provides review guidance regarding the determination of grid strength in order to meet Criterion 2.

During an audit of the supporting references conducted during October 14-16, 2015, the staff reviewed the BOL grid test data and methodology used to define the BOL grid critical buckling force, P(crit). The staff noted that the stress-strain curves indicated potential limited plastic deformation which occurred before the onset of a more general plastic deformation state. This point of potential limited plastic deformation occurred below the chosen P(crit). This has caused the staff to question the ability of the chosen P(crit) value to ensure compliance with GDCs 2 and 27.

Justify the chosen grid P(crit) values. If plastic deformation is allowed, then address RCCA insertability to demonstrate compliance with GDC 27.

Response

The through-grid long pulse test for BOL and EOL grids were performed according to the CENPD-178-P. The maximum load (P_{crit}) before the load begins to decrease with increasing deflection is conservatively selected as the through-grid crush strength. [

]TS

The outside diameter of the guide tubes was measured after grid crushed to show that the control rod insertability is maintained. The measured diameter of guide tubes satisfied the drawing dimension without permanent deformation. Therefore, the control rod insertability is maintained.

The technical report APR1400-Z-M-NR-14010-P Rev.0 is revised to include these test results with corresponding figures for the BOL and EOL grids.

The topical report APR1400-F-M-TR-13001-P Rev.0 will be revised to replace the pendulum test result with long pulse test result in the appendix A.2.3 because through-grid long pulse test was performed according to CENPD-178-P. The changed contents are in the attached markup.

TS

Figure 4.2.14-1 Impact Force and Deflection versus Run Number

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Report

Technical Report APR1400-Z-M-NR-14010-P Rev.0 is revised as the submitted Technical Report.
Topical Report APR1400-F-M-TR-13001-P Rev.0 will be revised as indicated in the attached markup.

1. INTRODUCTION

PLUS7 fuel was jointly developed from 1999 through 2002 with Westinghouse to enhance the fuel performance relative to Guardian fuel. In the process of the design, various out-of-pile mechanical, thermal, hydraulic, and vibration characteristic tests were performed.

For the in-pile tests, four lead test assemblies (LTAs) were loaded in an OPR1000 nuclear power plant in the Republic of Korea and irradiated from 2002 through 2007. Additionally, four commercial surveillance assemblies (CSAs) were examined in Yonggwang unit 5 for three cycles from 2006 to 2010. The in-pile performance of PLUS7 fuel was confirmed through poolside examinations (PSEs) of the LTAs and CSAs, and hot-cell examinations of the LTA. Based on the successful in-reactor performance of the LTAs and CSAs, more than 2,300 PLUS7 fuel assemblies have been supplied to OPR1000 nuclear power plants from 2006 to 2012. PLUS7 fuel will also be supplied to APR1400 nuclear power plants from the initial cores.

PLUS7 fuel has the following advanced design features with respect to Guardian fuel:

- High burnup performance
  Batch average burnup increase from 45,000 to 55,000 MWD/MTU
- High thermal performance
  Overpower margin increase by more than 10%
- High mechanical strength
  Mid grid dynamic buckling strength increase by ~~45%~~ 35%
- Improved economy
  Enhanced uranium utilization (optimized H/U ratio) and neutron economy
- Improved fretting wear resistance
  Increased grid-to-rod fretting wear resistance with the conformal grid springs and dimples
- Multi-devices for debris filtering
  Improved debris filtering efficiency with a small-hole bottom nozzle and the protective grid
- Enhanced fuel production
  Standardized design and manufacturing processes

This report describes the design features, evaluation results, and in-reactor performance results of PLUS7 fuel.

In Chapter 2, the mechanical design features, design criteria and evaluation results of PLUS7 fuel assembly and components are described.

Chapter 3 covers the design and the evaluation results of the PLUS7 fuel rods with ZIRLO™ cladding up to 60,000 MWD/MTU.

In Chapter 4, the fuel experiences of PLUS7 are described based on the operating experiences, including results of the pool-side examinations and hot-cell examinations of PLUS7 LTAs and CSAs.

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A.1.0 INTRODUCTION

The following tests were conducted to verify the hydraulic and mechanical characteristics of the PLUS7 fuel assembly:

Through-Grid Long Pulse Test

Through-Grid Buckling Strength

Test Item	Test Objectives	Facility
1. Fuel Assembly Vibration Test	To determine the flow induced fuel assembly vibration characteristics	FACTS
2. Fuel Rod Fretting Wear Test	To evaluate the fuel rod fretting wear	VIPER
3. ~~Mid Grid Crush Test~~	To obtain ~~dynamic strength and stiffness~~	Grid Impact Tester
4. Top Nozzle Mechanical Test	To obtain strain levels and displacements of the adapter plate and holddown plate at selected locations as a function of axial loading	FA Test Facility
5. DFBN Mechanical Test	To obtain fuel assembly mechanical characteristics	FA Test Facility
6. Grid Hang-up Test	To confirm FA to FA grid hang-up performance	FA to FA test
7. FACTS Hydraulic Pressure Drop Test	To measure the fuel assembly and component pressure drop	FACTS
8. Grid Spring Test	To determine the inner and outer cell spring load deflection characteristics of grid assemblies.	Grid Spring Tester
9. Fuel Assembly Lift-off Test	To determine the flow rates at which the fuel assembly lifts off	FACTS

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A.2.3 Mid Grid Crush Test

1.0 Introduction and Objectives

The dynamic crush strength of the mid grid is required to obtain the structural characteristics to show that both seismic and LOCA loads are met.
The specific test objectives for the dynamic crush test of the PLUS7 ZIRLO mid grid design at elevated temperatures were as follows:

- To obtain the impact force as a function of impact velocity
- To determine the grid ultimate load capability
- To characterize the grid failure mode
- To obtain the data to determine the grid dynamic stiffness

2.0 Test Conditions

The dynamic crush test was performed at operating temperature and the pendulum inertial mass was calculated as the weight of one span of PLUS7 fuel assembly.

The pendulum angle was increased by 1° from 7° until grid crushed.

- Elevated temperature: 600°F±20°F
- Pendulum inertial mass: [ ]TS
- Pendulum initial angle: 7°

3.0 Test Results

Twelve grid crush tests were sequentially performed. The PLUS7 ZIRLO mid grid crush test results are summarized as follows:

Table A.2.3-1 PLUS7 ZIRLO Mid grid Crush Test Results

[ ]TS

4.0 Summary and Conclusion

The crush strength values for the PLUS7 ZIRLO mid grid tested with rod-in-cell are shown in Figure A.2.3-3.

A summary of the dynamic crush test results is as follows:

- Dynamic Crush Strength:

A.2.3 Through-Grid Long Pulse Test

1.0 Introduction and Objectives

The through-grid buckling strength of the mid grid is required to show that seismic and LOCA loads are met. The specific test objectives for the through-grid long pulse test of the PLUS7 ZIRLO mid grid design at room temperatures are as follows:

- To obtain the data to determine the through-grid buckling strength
- To characterize the grid failure mode

2.0 Test Conditions

The through-grid long pulse tests were performed at room temperature. The grids were tested as a grid span section of fuel assembly, with drilled end plates supporting the short fuel rods and guide tubes. Each grid assembly was mounted with one vertical grid face contacting back plate that is rigidly fastened to the test cell wall. The load pulse was applied to grid assembly by the hydraulic actuator, which was controlled by the hydraulic control unit. The impact load was increased until the load decrease significantly and/or the grid has experienced observable permanent deformation. A schematic of the through-grid long pulse test arrangement is shown in Figure A.2.3-1.

3.0 Test Results

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The lower 95% confidence value of true mean is [ ]TS.

- Dynamic Grid Stiffness:

  The average dynamic stiffness using an impact duration method is [ ]TS.

- Impact Performance Factor:

  The impact performance factor $(P/\sqrt{K})$ for the test sample is [ ]TS.

4.0 Summary and Conclusion

The through-grid buckling strength and deformation curves for the PLUS7 ZIRLO mid grids are shown in Figure A.2.3-2.

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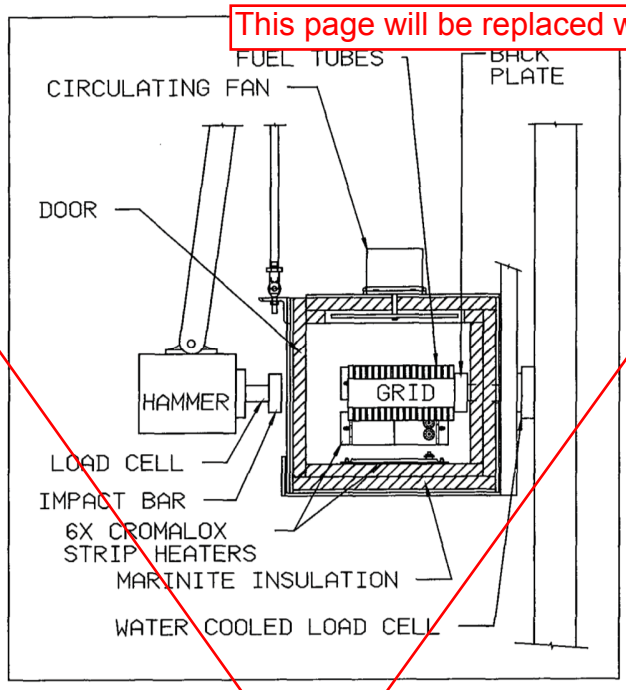

Figure A.2.3-1 Dynamic Crush Test Apparatus Detail

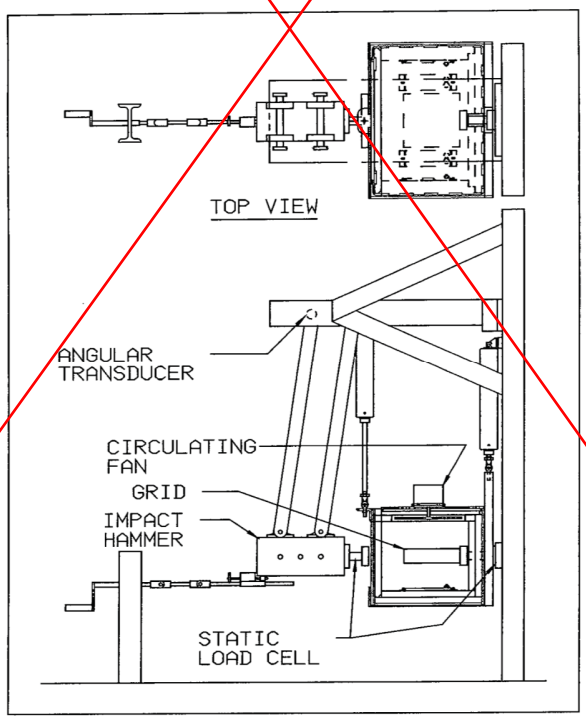

Figure A.2.3-2 Dynamic Crush Test Apparatus

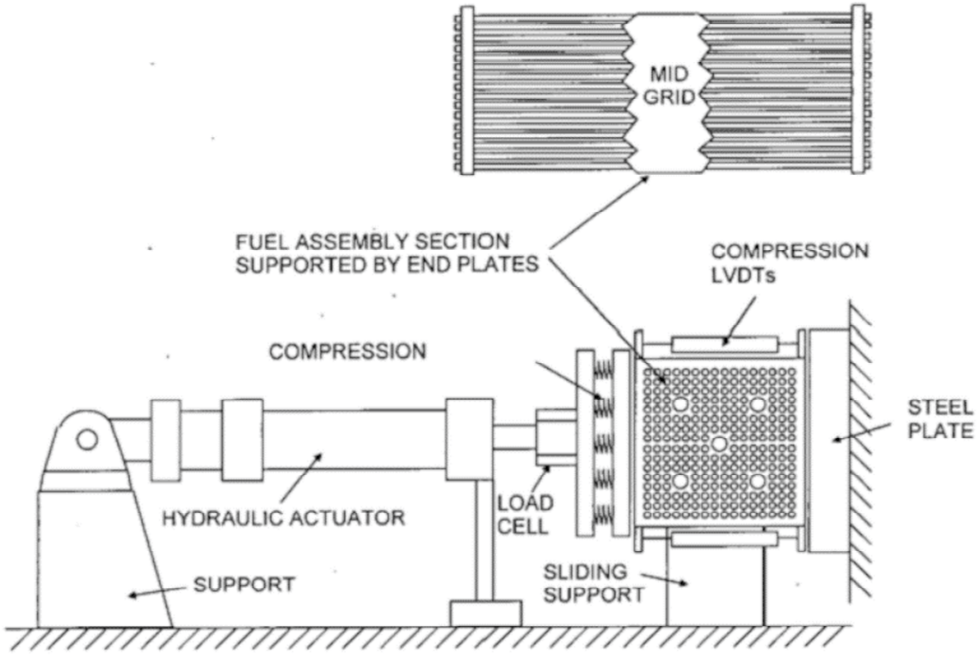

Figure A.2.3-1 Through-Grid Long Pulse Test Arrangement

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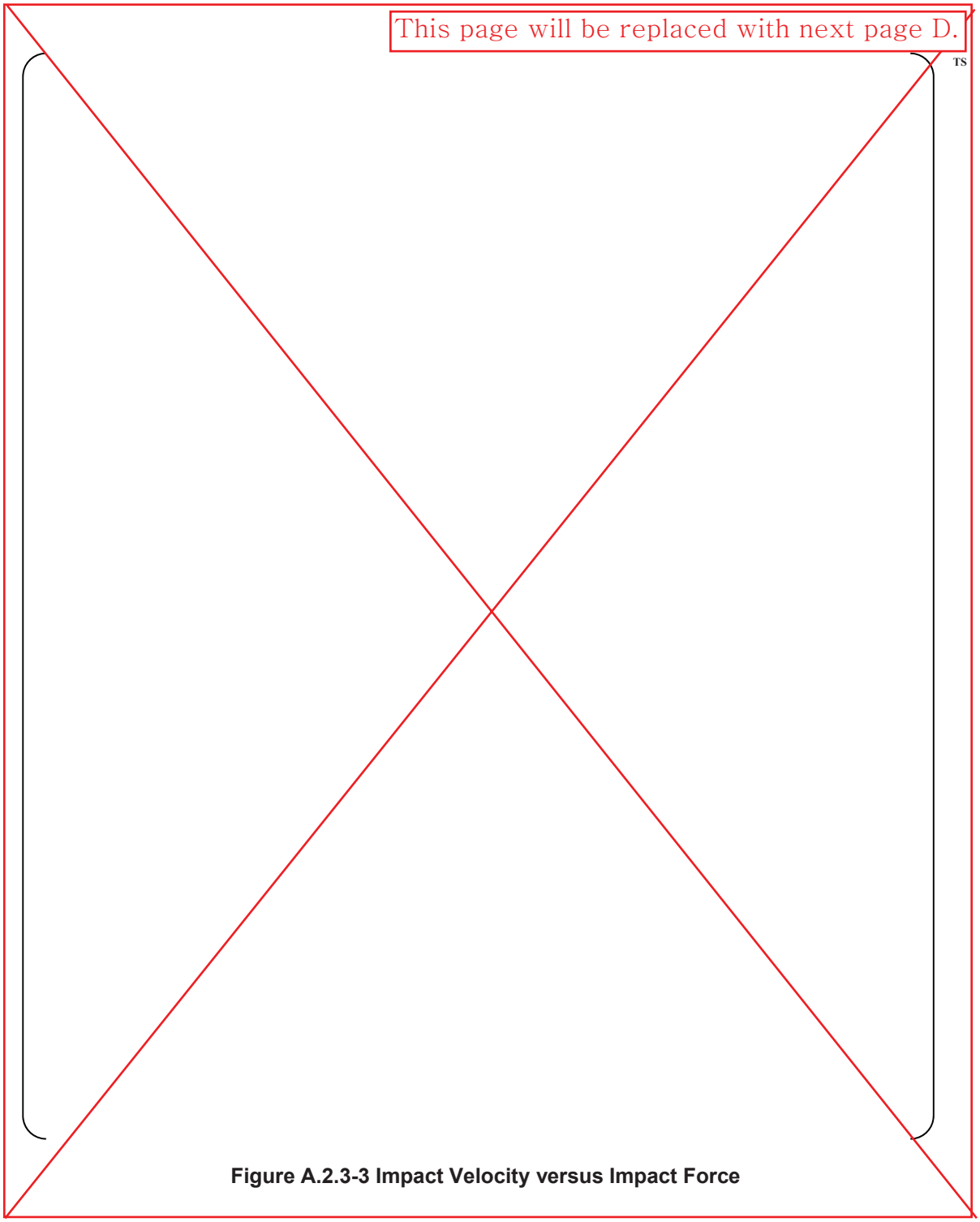

Figure A.2.3-3 Impact Velocity versus Impact Force

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Figure A.2.3-2 Impact Force & Deformation versus Run Number