

# Contents

<b>1 Introduction</b> . . . . .	1
1.1 Background to the Establishment of the AESJ Investigation Committee . . . . .	1
1.2 Activities of the AESJ Investigation Committee . . . . .	2
1.3 Structure of the Report . . . . .	4
<b>2 Overview of Nuclear Power Station</b> . . . . .	7
2.1 Overview of Facilities in the Fukushima Daiichi Nuclear Power Station . . . . .	7
2.1.1 Main Facilities Including Safety Equipment . . . . .	7
2.1.2 Facilities for Accident Management Measures . . . . .	14
2.1.3 Seismic Resistant Design and Tsunami Resistant Design for Facilities . . . . .	15
2.2 Overview of Facilities in the Power Stations Other Than the Fukushima Daiichi Nuclear Power Station . . . . .	17
2.2.1 The Fukushima Daini Nuclear Power Station . . . . .	17
2.2.2 The Onagawa Nuclear Power Station . . . . .	17
2.2.3 The Tokai Daini Nuclear Power Station . . . . .	17
<b>3 Overview of the Accident at the Fukushima Daiichi Nuclear Power Station</b> . . . . .	19
3.1 Damage Caused by the Earthquake and Tsunami . . . . .	19
3.2 Unit 1 . . . . .	20
3.3 Unit 2 . . . . .	27
3.4 Unit 3 . . . . .	32
3.5 Unit 4 and Spent Fuel Pools . . . . .	37
3.6 Unit 5 and Unit 6 . . . . .	41

<b>4</b>	<b>Overview of Events Occurring at Power Stations Other Than the Fukushima Daiichi Nuclear Power Station</b>	43
4.1	The Fukushima Daini Nuclear Power Station	43
4.1.1	Overview of the Fukushima Daini Nuclear Power Station	43
4.1.2	Overview of the Earthquake and Tsunami	43
4.1.3	Influence of the Seismic Ground Motion and the Tsunami	44
4.1.4	Response Before the Arrival of the Tsunami	46
4.1.5	Response After the Arrival of the Tsunami	46
4.2	The Onagawa Nuclear Power Station	50
4.2.1	Overview of the Onagawa Nuclear Power Station	50
4.2.2	Overview of the Earthquake and Tsunami	50
4.2.3	Influence of the Seismic Ground Motion and Tsunami	51
4.2.4	Response Before the Arrival of the Tsunami	53
4.2.5	Response After the Arrival of the Tsunami	54
4.2.6	Tsunami Countermeasures Before the Accident	55
4.3	The Tokai Daini Nuclear Power Station	57
4.3.1	Overview of the Tokai Daini Nuclear Power Station	57
4.3.2	Overview of the Earthquake and Tsunami	57
4.3.3	Influence of the Seismic Ground Motion and Tsunami	58
4.3.4	Response Before the Arrival of the Tsunami	59
4.3.5	Response After the Arrival of the Tsunami	60
4.3.6	Tsunami Countermeasures Before the Accident	61
4.4	Summary Comparison	62
<b>5</b>	<b>Off-Site Response</b>	69
5.1	Emergency Response Plan Prior to the Accident	71
5.2	Overview of Emergency Actions Taken in the Event of the Accident	72
5.2.1	Initial Response Actions During an Emergency	72
5.2.2	Urgent Protective Actions for Residents (Evacuation, etc.)	72
5.2.3	Additional Early Protective Actions	76
5.2.4	Transition to Long-term Protective Actions	77
5.3	Individual Issues of Emergency Actions	78
5.3.1	Residents' Evacuation	78
5.3.2	Standard Limits for Radionuclides in Foods	83
5.3.3	Radiation and Exposure Dose Measurements	87
5.3.4	Environmental Pollution by Radioactive Material and Decontamination	99
5.4	Radioactive Material Release and INES Evaluation	104
5.4.1	Estimated Amount of Radioactive Material Release	104

5.4.2	INES Evaluation	109
5.5	Communication After the Accident	112
5.5.1	Miscommunication Related to the Actors Involved	113
5.5.2	Communications to the Public by AESJ	114
5.6	Off-site Support Activities	115
5.6.1	Actual Conditions of the Off-site Distribution	115
5.6.2	Status of Securing Materials and Equipment	116
5.6.3	Securing Power Supply Vehicles	117
5.6.4	Securing Fire Engines	118
	References	118
<b>6</b>	<b>Accident Analysis and Issues</b>	121
6.1	Overview of Accident Analysis	121
6.1.1	Items in the Analysis	122
6.1.2	Evaluation of Accident Progression Behavior	128
6.1.3	Evaluation of Radioactive Material Release	145
6.2	Concept of Nuclear Safety	153
6.2.1	Basic Principles of Nuclear Safety	154
6.2.2	Risk Assessment and Utilization of Risk Information	156
6.2.3	Safety Goals and Risk Reduction	161
6.2.4	Safety of Nuclear Power Generation and Mechanism of Ensuring Safety	164
6.2.5	Relationship Between Nuclear Safety and Nuclear Security	167
6.3	Defence in Depth	170
6.3.1	Defence in Depth Perception in Japan	171
6.3.2	Analysis of Defence in Depth in the Light of the Fukushima Daiichi NPS Accident	174
6.3.3	Defence in Depth Deepening and Future Steps	178
6.4	Plant Design	183
6.4.1	Analysis on Design	183
6.4.2	System Safety in Plant Design	187
6.4.3	Discussion Points on the Isolation Condenser (IC)	195
6.4.4	Materials and Structural Integrity	204
6.4.5	Ageing Degradation	212
6.5	Accident Management	215
6.5.1	Radioactive Material Containment Function of Primary Containment Vessel	216
6.5.2	Reactor Instrumentation Systems (Reactor Water Level Instrumentation)	218
6.5.3	Coolant Injection and Heat Removal Systems	222
6.5.4	Importance of Management	225
6.5.5	Multiple Reactors in the Same Site	231

6.6	External Events . . . . .	234
6.6.1	Seismic Hazard Management . . . . .	235
6.6.2	Tsunami Hazard Management . . . . .	245
6.6.3	External Events and Natural Hazards Management . . . . .	250
6.7	Radiation Monitoring and Environment Remediation Activities . . . . .	254
6.7.1	Environmental Radiation Monitoring as an Initial Response to the Environmental Remediation . . . . .	254
6.7.2	Effects of Radiation . . . . .	258
6.7.3	Decontamination Measures: Legal Framework and Guidelines . . . . .	262
6.7.4	Establishment of Areas Subject to Decontamination . . . . .	266
6.7.5	Decontamination Framework of the Central and Local Governments . . . . .	269
6.7.6	Decontamination Technology . . . . .	271
6.7.7	Volume Reduction . . . . .	279
6.7.8	Temporary Storage Yard, Interim Storage Facilities and Final Disposal Site for Waste Generated from Decontamination . . . . .	282
6.7.9	Environmental Remediation Activities by the Atomic Energy Society of Japan (AESJ) . . . . .	288
6.8	Simulation Analysis . . . . .	292
6.8.1	Computational Science and Technology Analysis . . . . .	292
6.8.2	Simulations by SPEEDI . . . . .	305
6.8.3	Event Sequence Analysis and Source Term Assessment . . . . .	310
6.9	Emergency Preparedness and Response . . . . .	320
6.9.1	Urgent Protective Actions . . . . .	321
6.9.2	Emergency Management and Operations . . . . .	334
6.9.3	Off-site Emergency Response Other Than Disaster Prevention Measures . . . . .	336
6.10	Nuclear Security, Physical Protection, and Safeguards . . . . .	339
6.10.1	Nuclear Security and Physical Protection of Nuclear Material . . . . .	339
6.10.2	Safeguards and Nuclear Material Management and Accountability . . . . .	351
6.11	Human Resources and Human Factors . . . . .	356
6.11.1	Human Factors . . . . .	357
6.11.2	Human Resources in Nuclear Field . . . . .	376
6.11.3	Responsibility and Duty of the Chief Reactor Engineer . . . . .	386
6.12	Relationship with International Society . . . . .	389
6.13	Information Dissemination . . . . .	396

	Appendix: Items Related to Accident Progression That Require Further Investigation and Consideration . . . . .	399
	References . . . . .	419
<b>7</b>	<b>Analysis and Issues on Nuclear Safety System . . . . .</b>	<b>425</b>
7.1	Safety Regulatory System . . . . .	426
7.1.1	Analysis on Safety Regulations . . . . .	430
7.1.2	Conditions and Future Approach on the Regulatory System . . . . .	436
7.1.3	Regulatory Framework for Ensuring Nuclear Safety . . . . .	442
7.2	Nuclear Safety in the Industrial Community . . . . .	446
7.2.1	The Role of Licensees . . . . .	446
7.2.2	Licensees' Response to Nuclear Accidents . . . . .	447
7.2.3	Lessons Learned from the Fukushima Daiichi Accident . . . . .	448
7.2.4	Future Issues of the Nuclear Power Industry . . . . .	453
7.3	R&D and Safety Research System . . . . .	454
7.4	International System . . . . .	458
7.5	The Role of Atomic Energy Society of Japan . . . . .	463
	References . . . . .	467
<b>8</b>	<b>Root Causes of the Accident and Recommendations . . . . .</b>	<b>469</b>
8.1	Root Cause Analysis . . . . .	469
8.1.1	Direct Causes . . . . .	469
8.1.2	Underlying Causes . . . . .	471
8.2	Recommendations . . . . .	473
8.2.1	Recommendation I (Basic Items of Nuclear Safety) . . . . .	475
8.2.2	Recommendation II (Items Related to Direct Causes) . . . . .	478
8.2.3	Recommendation III (Items Related to Organizational Causes Among Underlying Causes) . . . . .	484
8.2.4	Recommendation IV (Common Items) . . . . .	488
8.2.5	Recommendation V (Items Related to Restoration) . . . . .	491
8.2.6	Conclusion . . . . .	493
<b>9</b>	<b>Post-accident Management in Progress . . . . .</b>	<b>495</b>
9.1	Treatment and Cleanup of Contaminated Water . . . . .	496
9.2	Handling of Damaged Fuel . . . . .	506
9.2.1	Unloading of Fuel Assemblies from Spent Fuel Pools and Their Storage . . . . .	507
9.2.2	Removal and Storage of Fuel Debris . . . . .	508
9.2.3	Fuel Inventory and the Likelihood of Recriticality . . . . .	514
9.3	Decommissioning and Treatment and Disposal of Radioactive Waste . . . . .	518
9.3.1	Introduction . . . . .	518
9.3.2	Decommissioning . . . . .	519
9.3.3	Processing and Disposal of Radioactive Waste . . . . .	523
9.3.4	Summary . . . . .	525

9.4	Long-Term Stable Storage of Major Systems and Components . . . . .	526
9.4.1	Analyses and Countermeasures . . . . .	526
9.4.2	Reactor Pressure Vessel and Primary Containment Vessel . . . . .	529
9.5	Long-Term Healthcare of Residents and Workers . . . . .	533
	References . . . . .	536
	<b>Afterwords . . . . .</b>	<b>537</b>
	<b>Appendix 1 List of the Members of AESJ Investigation Committee on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station . . . . .</b>	<b>539</b>
	<b>Appendix 2 Past Records of the Activities of the Investigation Committee . . . . .</b>	<b>545</b>
	<b>Appendix 3 List of Abbreviations . . . . .</b>	<b>549</b>
	<b>Index . . . . .</b>	<b>553</b>