4. TRISO-COATED PARTICLE FUEL PHENOMENON IDENTIFICATION AND RANKING TABLES (PIRTS)

Six summary TRISO-coated particle fuel PIRT tables are presented in this chapter, one each for Manufacturing (Table 4-1), Operations (Table 4-2), Depressurized Heatup Accident (Table 4-3), Reactivity Accident (Table 4-4), Depressurization Accident with Water Ingress (Table 4-5), and Depressurization Accident with Air Ingress (Table 4-6).

The summary information in each PIRT table is presented in an eight-column format.

Column 1 identifies the "Factor, Characteristic, or Phenomenon" for which importance and a knowledge levels were assessed by the TRISO-coated particle fuel PIRT panel.

Column 2 contains the definition prepared by the panel for each entry in Column 1.

Columns 3 and 4 contain an importance rank of either High (H), Medium (M) or Low (L) and knowledge level assessment between 1 and 9 given by the Idaho National Engineering and Environmental Laboratory (INEEL) panel member.

Columns 5 and 6 contain input of the Oak Ridge National Laboratory (ORNL) panel member and Columns 7 and 8 contain the input of the Sandia National Laboratories (SNL) panel member.

An importance rank of "H" indicates that the factor, characteristic or phenomenon had a dominant or controlling impact on the primary evaluation criterion, i.e., fission product release. An importance rank of "L" indicates a small influence. An importance rank of "M" indicates a moderate influence. A knowledge assessment of "1" is used when there is little or no knowledge or understanding of the entry in Column 1 while a knowledge assessment of "9" is used when there is a complete knowledge and understanding. Numbers between 1 and 9 are assigned to indicate intermediate levels of knowledge and understanding.

The summary data for the six PIRT tables presented in this chapter were derived from the detailed PIRT inputs provided by each panel member for each of the six PIRTs. The detailed PIRT input provided by the panel members provides the importance and knowledge assessments as well as the rationales, with varying level of detail, for each. In addition and where possible, the panel members suggested closure efforts that might be undertaken for highly important factors, characteristics and phenomena for which the knowledge and understanding are not sufficiently developed.

Panel member importance and knowledge rankings, detailed rationales for the importance and knowledge rankings, and suggested closure rationales are found in the following appendices.

Appendix A	Manufacturing
Appendix B	Operations
Appendix C	Depressurized Heatup Accident
Appendix D	Reactivity Accident
Appendix E	Depressurization Accident with Water Intrusion
Appendix F	Depressurization Accident with Air Intrusion

Initially, the TRISO-coated particle fuel PIRT panel was tasked to prepare a PIRT for the TRISO-coated particle fuel Design phase. Importance ranks and knowledge levels, as well as the accompanying rationales, were developed by each panel member. The Design PIRT effort was discontinued when the PIRT effort expanded to include additional accident scenarios. Although the panel effort did not proceed to the same degree of completion as the other PIRTs summarized in Tables 4-1 through 4-6, the detailed Design PIRT information prepared by the panel members are thought to include significant insights. Therefore, the detailed INEEL, ORNL, and SNL PIRT inputs are provided in Appendix H.

Analyses and summaries of the PIRT results presented in Tables 4-1 through 4-6 and Appendices A through F are found in Chapter 5, TRISO-coated particle fuel PIRT Analysis and Summary.

The extensive phenomena accounted for in the TRISO-coated particle fuels PIRT tables may be viewed as an inventory of all of the basic phenomena that the PIRT panel considers to play a role in TRISO-coated particle fuel performance and the transport of fission products within the fuel components. However, the PIRT panel does not intend to imply that each and every factor, characteristic or phenomenon that has been identified must be explicitly and individually accounted for in the modeling or analysis of gas-cooled reactor fuel performance and fission product transport. The panel recognizes that it may prove feasible to model some of these phenomena to assess performance and fission product transport in the fuel in a way that adequately and effectively combines some of the individual phenomena into an integrated parameter(s). In such cases these PIRT tables will serve as a valuable "checklist" to support the assessment of the approach in which the basic TRISO PIRT phenomena are addressed.

Table 4-1 TRISO-Coated Particle Fuel Manufacturing Summary PIRT

		INEEL		ORNL		SNL**	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
Layer coating process specifications: Gases (levitation gas and coating gas)	Gases used to levitate and coat to create layer	M	8	H	8	-	-
Layer coating process specifications: Ratio of gases	Ratio of active gas to total gas, including concentration	H	7	H	7	-	-
Layer coating process specifications: Temperature	Temperature of coater	H	8	H	7	-	-
Layer coating process specifications: Coating Rate	The average deposition rate over space and time of the layer	H	8	H	6	-	-
Layer coating process specifications: Pressure	Pressure inside coater	L	3	L	4	-	-
Layer coating process specifications: Coater Size	Size is measured by the diameter of the coater	H	6	H	6	-	-
Layer coating process	Continuous vapor deposition TRISO coating without unloading of particles	H	6	H	4	-	-
Process control:	Correlation between measured process parameters and irradiation performance	H	6	H	6	-	-
Product control:	Correlation between measured product parameters and irradiation performance	M	6	H	5	-	-
Fuel Element: Particle overcoating (fuel form dependent)	Layer on outside of outer PyC added after coating	H	8	H	7	-	-
Fuel Element: Matrix and Binder	Filler mixed with resin	H	6	H	7	-	-
Fuel Element: Bonding strength (PyC to matrix)	Interfacial strength at the interface	L	6	M	7	-	-
Fuel Element: Compacting	Process of forming fuel element involving molding and pressing	H	7	H	7	-	-

Table 4-1 TRISO-Coated Particle Fuel Manufacturing Summary PIRT (continued)

		INEEL		ORNL		SNL**	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
Fuel Element: Carbonization	Baking full fuel element to drive off volatiles	L	6	M	7	-	-
Fuel Element: Heat Treatment	High temperature annealing to stabilize fuel form	L	7	M	7	-	-
Fuel Element: Impurities Control	Minimization of contamination of fuel form by process equipment (e.g., iron, chrome, etc)	H	7	H	7	-	-
Fuel Element: Tramp Uranium	Uranium introduced by raw materials, e.g., resin	H	8	H	8	-	-
Fuel Element: Strength	An overall measure of fuel element resistance to stresses that might occur during operation or accidents	H	8	H	8	-	-
Fuel Element: Initial particle defect fraction due to manufacture	Exposed kernel fraction	H	6	H	7	-	-
Outer PyC layer: Anisotropy (initial)	Difference in grain orientation along principal directions as measured by the BAF	H	8 FRG 6 US	H	5	-	-
Outer PyC layer: Porosity	Interconnected void accessible to the surface	M	8	M	7	-	-
SiC layer: Grain size and microstructure, e,g,, alignment	Size and orientation of the grains and the pores	H	8	H	6	-	-
SiC layer: Fracture strength	Mean tensile strength (Weibull parameter or equivalent)	H	6	H	6	-	-
SiC layer: Density	Mass per unit volume	H	8	H	8	-	-
SiC layer: Bonding strength (SiC to outer PyC)	Interfacial strength at the interface	L	6	L	2	-	-
SiC layer: Stoichiometry	Ratio of silicon to carbon (absence of gold spots, i.e., elemental Si)	H	6	H	6	-	-

Table 4-1 TRISO-Coated Particle Fuel Manufacturing Summary PIRT (continued)

		INEEL		ORNL		SNL**	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
SiC layer: Heavy metal dispersion	Amount of heavy metals dispersed in the layer present after manufacture	M	7	H	7	-	-
SiC layer: Defects	Initial undetected pinhole or other defects resulting from the manufacturing process	H	5	H	5	-	-
Inner PyC layer: Anisotropy (initial)	Difference in crystal orientation along principal directions as measured by the BAF	H	5	H	5	-	-
Inner PyC layer: Bonding strength (inner PyC to SiC)	Interfacial strength at the interface	H	6	H	3	-	-
Inner PyC layer: Porosity	Interconnected void accessible to the surface	M	5	H	7	-	-
Buffer layer: Thin or missing	Layer thickness less than specified or missing layer	H	7	H	7	-	-
Buffer layer: Density and open porosity	Mass per unit volume and interconnected void accessible to the surface	M	8	H	7	-	-
Kernel: Density	Mass per unit volume in final form	M	9	M	8	-	-
Kernel: Microstructure (UO2)	Grain size, pore structure (interconnectivity) and orientation in kernel	M	8	M	7	-	-

* KL = Knowledge Level
** Panel member declined to provide input due to lack of manufacturing background.

Table 4-2 TRISO-Coated Particle Fuel Operations Summary PIRT

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL*	Rank	KL	Rank	KL
Fuel element: Temperature	Local temperature in the fuel element	H	8	H	7	M	8
Fuel element: Fast fluence	Accumulated fast neutron fluence greater than 0.18 MeV	M	5	M	7	M	5
Fuel element: Power density	Power per pebble or compact (W)	L	6	M	7	M	6
Fuel element: Temperature difference	Temperature between center or centerline and surface in ºC	M	7	M	7	H	7
Fuel element: Temperature-time histories	Local temporal temperature of fuel element over its lifetime	H	7	H	7	M	7
Fuel element: Condensed phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	5	H	6	H	4
Fuel element: Gas phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	M	7	H	7	H	5
Fuel element: Corrosion by coolant impurities	Corrosion of the fuel element outer surface by part per million level of gaseous impurities in the helium coolant	M	6	M	7	M	4
Kernel: CO production	Formation of CO from excess oxygen released in fission	H UO_2 L UCO	8 UO_2 5 UCO	H	7	H	2
Kernel: Burnup	Fission of initial metal atoms	H	7	H	7	L	2
Kernel: Kernel swelling	Volumetric expansion of kernel resulting from fissioning	L	6	L	6	L	5
Kernel: Microstructure changes	Change in structure in kernel with burnup, including fission gas bubbles, grain growth and grain disintegration	L	6	M	6	H	5

Table 4-2 TRISO-Coated Particle Fuel Operations Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL*	Rank	KL	Rank	KL
Kernel: Fission product chemical form	Chemical speciation of fission products as a function of burnup and temperature	H	7	H	6	L	5
Kernel: Buffer interaction	Mechanical and chemical interactions between the kernel and buffer, e.g., chemical reactions at interface and displacement of buffer by kernel growth.	M	6	L	6	H	3
Kernel: Kernel migration (fuel dependent)	Kernel migration (fuel dependent)	M UO_2 L UCO	8 UO_2 8 UCO	H	7	H	3
Kernel: Fission product generation	Yield of fission products from uranium and plutonium fission	H	9	H	8	L	9
Kernel: Temperature gradient	Temperature gradient across the kernel	L	6	H	7	H	3
Kernel: Isotopic half life	The time lapse during which a mass of a particular isotope loses half of its radioactivity	M	9	M	8	L	9
Buffer Layer: Pressure	Gas pressure generated in the void volume associated with the buffer layer	H H	6 UO_2 7 UCO	H	6	H	4
Buffer Layer: Shrinkage	Radiation or otherwise induced dimensional change	M	6	M	6	M	2
Buffer Layer: Cracking	Shrinkage cracks produced in layer during operation	H	5	H	6	H	3
Buffer Layer: Carbonyl vapor species	M-CO species partial pressures	M	3	L	1	H	4
Buffer Layer: Temperature gradient	Temperature difference across the buffer layer	H	5	H	6	H	3
Buffer Layer: Condensed phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	M	5	M	5	H	2

Table 4-2 TRISO-Coated Particle Fuel Operations Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL*	Rank	KL	Rank	KL
Buffer Layer: Gas phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	M	5	M	6	H	5
Buffer Layer: Recoil effects	Buffer damage arising from capture of high-energy fission products	M	7	M	5	L	5
Inner PyC layer: Radiation induced creep	Strain release as a result of radiation induced dimensional change	H	5	H	5	L	4
Inner PyC layer: Fast fluence	Accumulated fast neutron fluence greater than 0.18 MeV	H	8	H	6	M	5
Inner PyC layer: Dimensional change	Unrestrained radial and tangential changes with fast fluence	H	7	H	5	M	4
Inner PyC layer: Anisotropy	Operation-induced (thermal + radiation) change in grain orientation along principal directions as measured by the BAF	H	8 FRG 8 US	H	5	L	3
Inner PyC layer: Cracking	Lengths, widths, and numbers of cracks produced in layer during operation	H	6	H	5	H	3
Inner PyC layer: Debonding	Separation of PyC layer from SiC layer	M	5	M	3	L	3
Inner PyC layer: Condensed phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	7	H	6	H	1
Inner PyC layer: Gas phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	7	H	7	H	4
SiC layer: Kernel interaction with SiC layer	Kernel migration (amoeba effect)	M	8	H	7	H	6

Table 4-2 TRISO-Coated Particle Fuel Operations Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL*	Rank	KL	Rank	KL
SiC layer: Fission product corrosion	Attack of layer by fission products, e.g., Pd	H	6	H	6	H	4
SiC layer: Heavy metal attack	Damage to layer due to fissioning of heavy metals dispersed in the layer	L	6	L	7	L	6
SiC layer: Cracking	Lengths, widths and numbers of cracks produced in layer during operation	H	7	H	6	H	1
SiC layer: Condensed phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	7	H	6	H	1
SiC layer: Gas phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	7	H	7	H	4
Outer PyC layer: Radiation induced creep	Strain release as a result of radiation induced dimensional change	L	6	M	5	L	3
Outer PyC layer: Dimensional change	Unrestrained radial and tangential changes with fast fluence	M	7	M	5	L	2
Outer PyC layer: Anisotropy	Operation-induced (thermal + radiation) change in grain orientation along principal directions as measured by the BAF	M	7	M	5	L	7
Outer PyC layer: Condensed phase diffusion	Solid state diffusion	H	7	H	6	M	1
Outer PyC layer: Gas phase diffusion	Transport through pores and void structures by vapors, e.g., noble gases	H	7	H	7	H	4

Table 4-2 TRISO-Coated Particle Fuel Operations Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL*	Rank	KL	Rank	KL
Outer PyC layer: Cracking	Lengths, widths and numbers of cracks produced in layer during operation	M	3	M	5	H	1

- KL = Knowledge Level

Table 4-3 TRISO-Coated Particle Fuel Depressurized Heatup Accident Summary PIRT

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL* (1)/(2)	Rank	KL* (1)/(2)	Rank	KL* (1)/(2)
Fuel Element: Irradiation history	The temperature, burnup and fast fluence history of the layer	H	5/5	H	7/5	H	3
Fuel Element: Condensed phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	M	5/5	H	6/5	M	2
Fuel Element: Gas phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure). Other factors include holdup, cracking, adsorption, site poisoning, permeability, sintering, and annealing	M	5/5	H	7/7	H	4
Fuel Element: Transport of metallic FPs through fuel element – Chemical form	Chemical stoichiometry of the chemical species that includes the radioisotope of interest	H	5/5	H	5/5	H	3
Outer PyC Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	7/7	H	7/7	H	4
Outer PyC Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	7/7	H	7/7	M	2
Outer PyC Layer: Layer oxidation	Uptake of oxygen by the layer through a chemical reaction	L	6/6	L	6/6	L	8
Outer PyC Layer: Stress state (compression/tension)	The state of the forces induced by external forces that are acting across the layer to resist movement	L	5/5	M	6/6	M	4
Outer PyC Layer: Intercalation	Trapping of species between sheets of the graphite structure	M	4/4	L	2/1	L	3

Table 4-3 TRISO-Coated Particle Fuel Depressurized Heatup Accident Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL* (1)/(2)	Rank	KL* (1)/(2)	Rank	KL* (1)/(2)
Outer PyC Layer: Trapping	Adsorption of fission products on defects	M	4/4	L	2/1	L	3
Outer PyC Layer: Cracking	Lengths, widths and numbers of cracks produced in layer during operation or an accident	H	5/5	H	5/5	H	2
SiC Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	7/7	H	7/5	H	4
SiC Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	7/7	H	7/5	M	2
SiC Layer: Thermal deterioration/decomposition	Decline in the quality of the layer due to thermal loading	H	8/6	H	7/5	M	3
SiC Layer: Fission product corrosion	Attack of layer by fission products, e.g., Pd	H	7/5	H	7/5	L	3
SiC Layer: Heavy metal diffusion	Diffusion of heavy metals through the intact layer	L	3/3	L	5/5	M	2
SiC Layer: Layer oxidation	Uptake of oxygen by the layer through a chemical reaction	M	6/6	M	5/5	L	3
SiC Layer: Fission product release through undetected defects	Passage of fission products from the buffer region through defects in the SiC layer	H	6/6	H	5/5	H	3
SiC Layer: Fission product release through failures, e.g., cracking	Passage of fission products from the buffer region through regions in the SiC layer that fail during operation or an accident	H	7/6	H	6/5	H	3
SiC Layer: Thermodynamics of the SiC-fission product system	Chemical form of fission products including the effects of solubility, intermetallics, and chemical activity	H	7/7	H	7/5	H	4

Table 4-3 TRISO-Coated Particle Fuel Depressurized Heatup Accident Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL* (1)/(2)	Rank	KL* (1)/(2)	Rank	KL* (1)/(2)
SiC Layer: Sintering	Change of SiC microstructure as a function of temperature	L	5/5	L	7/7	M	6
Inner PyC Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	7/7	H	7/6	H	6
Inner PyC Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	7/7	H	7/7	M	2
Inner PyC Layer: Pressure loading (Fission products)	Stress loading of the layer by increased pressure from fission products	M	8/8	M	7/7	L	2
Inner PyC Layer: Pressure loading (Carbon monoxide)	Stress loading of the layer by carbon monoxide by increased pressure	H UO_2 L UCO	7/7	H	7/7	H	2
Inner PyC Layer: Layer oxidation	Reaction of pyrolytic graphite with oxygen released from the kernel	L	5/5	L	7/7	M	3
Inner PyC Layer: Stress state (compression/tension)	The state of the forces induced by external forces that are acting across the layer to resist movement	M	6/6	M	7/7	L	2
Inner PyC Layer: Cracking	Lengths, widths and numbers of cracks produced in layer during accident	H	5/5	H	6/6	H	1
Inner PyC Layer: Intercalation	Trapping of species between the basal planes of the structure	M	6/6	L	1/1	M	2
Inner PyC Layer: Trapping	Adsorption of fission products on defects	L	6/6	L	2/1	No entry	No entry

Table 4-3 TRISO-Coated Particle Fuel Depressurized Heatup Accident Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL* (1)/(2)	Rank	KL* (1)/(2)	Rank	KL* (1)/(2)
Buffer Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	7/7	H	7/7	H	4
Buffer Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	7/7	H	7/7	L	1
Buffer Layer: Response to kernel swelling	Mechanical reaction of the layer to the growth of the kernel via swelling	L	4/4	L	7/7	M	4
Buffer Layer: Maximum fuel gaseous fission product uptake	Maximum loading of fission products that can deposit from the gas phase onto surfaces of materials surrounding the fuel kernel	L	2/2	L	7/7	L	2
Buffer Layer: Layer oxidation	Reaction of buffer layer with-oxide materials in the kernel	H	6/6	L	7/7	H	3
Buffer Layer: Thermal gradient	Change in temperature with distance	L	6/6	L	7/7	H	2
Buffer Layer: Irradiation and thermal shrinkage	Dimension changes in the buffer layer or changes in its porosity produced by irradiation or by exposure to elevated temperatures	L	7/7	L	6/6	L	5
Kernel: Maximum fuel temperature	Maximum fuel temperature attained by the fuel kernel during the accident	H	7/7	H	7/7	H	5
Kernel: Temperature vs. time transient conditions	The time-dependent variation of fuel temperature with time	H	7/7	H	7/7	H	4
Kernel: Energy Transport: Conduction within kernel	Flow of heat within a medium from a region of high temperature to a region of low temperature	M	6/6	L	7/7	M	3

Table 4-3 TRISO-Coated Particle Fuel Depressurized Heatup Accident Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL* (1)/(2)	Rank	KL* (1)/(2)	Rank	KL* (1)/(2)
Kernel: Thermodynamic state of fission products	Chemical and physical state of fission products	H	7/7	H	6/6	H	5
Kernel: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	7/7	H	6/6	H	3
Kernel: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	7/7	H	6/4	H	3
Kernel: Oxygen flux	Mass transport of oxygen per unit surface area per unit time	M UO_2 L UCO	6/6	L	3/3	H	3
Kernel: Grain growth	Enlargement of grains as a result of diffusion	L	4/4	L	3/3	L	8
Kernel: Buffer carbon-kernel interaction	Chemical reaction between carbon and the fuel (UO2) to form UC2 and CO (gas)	H	6/6	L	5/5	H	3

* KL = Knowledge Level
(1) First entry is knowledge level for fuel temperatures ≤ 1600 °C
(2) Second entry is knowledge level for fuel temperatures > 1600 °C

Table 4-4 TRISO-Coated Particle Fuel Reactivity Accident Summary PIRT

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL*	Rank	KL*	Rank	KL*
Fuel Element: Irradiation history	The temperature, burnup and fast fluence history of the layer	M	8	H	7	H	1
Fuel Element: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	6	H	6	L	2
Fuel Element: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure). Other factors include holdup, cracking, adsorption, site poisoning, permeability, sintering, and annealing	H	5	H	7	H	2
Fuel Element: Transport of metallic FPs through fuel element – Chemical form	Chemical stoichiometry of the chemical species that includes the radioisotope of interest	H	5	M	5	M	8
Outer PyC Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	L	8	H	7	L	3
Outer PyC Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	L	8	L	7	L	2
Outer PyC Layer: Layer oxidation	Uptake of oxygen by the layer through a chemical reaction	M	6	L	6	L	3
Outer PyC Layer: Stress state (compression/tension)	The state of the forces induced by external forces that are acting across the layer to resist movement	M	7	L	6	L	2
Outer PyC Layer: Intercalation	Trapping of species between sheets of the graphite structure	L	No entry	L	1	L	3

Table 4-4 TRISO-Coated Particle Fuel Reactivity Accident Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL*	Rank	KL*	Rank	KL*
Outer PyC Layer: Trapping	Adsorption of fission products on defects	L	No entry	L	2	L	3
SiC Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	L	No entry	L	7	L	2
SiC Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	L	No entry	L	7	L	2
SiC Layer: Thermal deterioration/decomposition	Decline in the quality of the layer due to thermal loading	L	No entry	L	7	L	4
SiC Layer: Fission product corrosion	Attack of layer by fission products, e.g., Pd	L	No entry	L	7	H	6
SiC Layer: Heavy metal diffusion	Diffusion of heavy metals through layer	L	5	M	5	L	2
SiC Layer: Layer oxidation	Uptake of oxygen by the layer through a chemical reaction	M	5	L	5	L	5
SiC Layer: Fission product release through undetected defects, e.g., cracking	Passage of fission products from the buffer region through regions in the SiC layer that fail during operation or an accident	L	5	L	7	L	2
SiC Layer: Fission product release through failures, e.g., cracking	Passage of fission products from the buffer region through regions in the SiC layer that fail during operation or an accident	H	6	H	5	H	7
SiC Layer: Thermodynamics of the SiC-fission product system	Chemical form of fission products including the effects of solubility, intermetallics, and chemical activity	L	5	L	7	L	4
SiC Layer: Sintering	Change of graphite microstructure as a function of temperature	L	5	L	7	L	6

Table 4-4 TRISO-Coated Particle Fuel Reactivity Accident Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL*	Rank	KL*	Rank	KL*
Inner PyC Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	6	H	7	H	2
Inner PyC Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	L	7	L	7	L	2
Inner PyC Layer: Pressure loading (Fission products)	Stress loading of the layer by increased pressure from fission products	H	7	H	4	H	5
Inner PyC Layer: Pressure loading (Carbon monoxide)	Stress loading of the layer by carbon monoxide by increased pressure	H	7	H	4	H	3
Inner PyC Layer: Layer oxidation	Reaction of pyrolytic graphite with oxygen released from the kernel	M	5	L	7	L	4
Inner PyC Layer: Stress state (compression/tension)	The state of the forces induced by external forces that are acting across the layer to resist movement	M	7	L	4	H	2
Inner PyC Layer: Intercalation	Trapping of species between the basal planes of the structure	M	5	L	1	L	4
Buffer Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	7	H	6	H	4
Buffer Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	7	H	7	L	2
Buffer Layer: Response to kernel swelling	Mechanical reaction of the layer to the growth of the kernel via swelling	H	4	H	3	H	7

Table 4-4 TRISO-Coated Particle Fuel Reactivity Accident Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL*	Rank	KL*	Rank	KL*
Buffer Layer: Maximum fuel gaseous fission product uptake	Maximum loading of fission products that can deposit from the gas phase onto surfaces of materials surrounding the fuel kernel	H	4	H	5	M	2
Buffer Layer: Layer oxidation	Reaction of buffer layer with-oxide materials in the kernel	L	5	L	7	L	4
Buffer Layer: Thermal gradient	Change in temperature with distance	M	7	H	2	L	5
Buffer Layer: Irradiation and thermal shrinkage	Dimension changes in the buffer layer or changes in its porosity produced by irradiation or by exposure to elevated temperatures	L	7	M	5	L	7
Kernel: Maximum fuel temperature	Maximum fuel temperature attained by the fuel kernel during the accident	H	7	H	6	H	8
Kernel: Temperature vs. time transient conditions	The time-dependent variation of fuel temperature with time	H	7	H	7	H	8
Kernel: Energy deposition (total)	Amount of fission energy generated in kernel during reactivity event (j/gm heavy metal because of Pu)	H	7	H	4	H	7
Kernel: Energy deposition rate	Rate at which fission energy is generated in kernel	H	7	M	8	M	6
Kernel: Energy Transport: Conduction within kernel	Flow of heat within a medium from a region of high temperature to a region of low temperature	M	7	H	5	H	6
Kernel: Thermodynamic state of fission products	Chemical and physical state of fission products	H	7	H	6	H	7

Table 4-4 TRISO-Coated Particle Fuel Reactivity Accident Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL*	Rank	KL*	Rank	KL*
Kernel: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	5	H	5	M	6
Kernel: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	5	H	6	H	6
Kernel: Oxygen flux	Mass transport of oxygen per unit surface area per unit time	L	No entry	L	3	M	5
Kernel: Grain growth	Enlargement of grains as a result of diffusion	M	5	L	5	L	7
Kernel: Buffer carbon-kernel interaction	Chemical reaction between carbon and the fuel (UO2) to form UC2 and CO (gas)	L	6	L	5	H	2

* KL = Knowledge Level

Table 4-5 TRISO-Coated Particle Fuel Depressurization Accident with Water Ingress Summary PIRT

		INEEL		ORNL		SNL	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
Fuel Element: Irradiation history	The temperature, burnup and fast fluence history of the layer	M	7	H	7	H	3
Fuel Element: Condensed phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	6	H	4	M	1
Fuel Element: Gas phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure). Other factors include holdup, cracking, adsorption, site poisoning, permeability, sintering, and annealing	H	5	H	7	H	4
Fuel Element: Transport of metallic FPs through fuel element – Chemical form	Chemical stoichiometry of the chemical species that includes the radioisotope of interest	H	7	H	5	H	4
Fuel Element: Chemical attack by water – Kinetics	Rate of reaction per unit surface area as a function of temperature and partial pressure of steam	H	6	H	4	H	4
Fuel Element: Chemical attack by water – Catalysis	Modification of the reaction rate by fission products or impurities	M	5	M	4	H	4
Fuel Element: Chemical attack by water – changes in chemical form of fission products	Changes in chemical form resulting from oxidizing or reducing fission products	H	7	H	4	H	5
Fuel Element: Chemical attack by water – Changes in graphite properties	Changes in diffusivity, porosity, adsorptivity, etc.	M	6	H	4	H	2
Fuel Element: Chemical attack by water – Holdup reversals	Release of graphite FP inventory	M	6	H	4	L	5

Table 4-5 TRISO-Coated Particle Fuel Depressurization Accident with Water Ingress Summary PIRT (continued)

		INEEL		ORNL		SNL	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
Fuel Element: Chemical attack by water – Temperature distributions	Impact of graphite oxidation on temperature distribution through material	H	8	H	4	H	5
Outer PyC Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	M	6	M	5	H	6
Outer PyC Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	M	6	M	7	M	2
Outer PyC Layer: Layer oxidation	Uptake of oxygen by the layer through a chemical reaction	H	7	H	4	H	2
Outer PyC Layer: Stress state (compression/tension)	The state of the forces induced by external forces that are acting across the layer to resist movement	L	8	M	6	L	2
Outer PyC Layer: Intercalation	Trapping of species between sheets of the graphite structure	M	4	L	2	L	2
Outer PyC Layer: Trapping	Adsorption of fission products on defects	M	4	L	3	L	2
Outer PyC Layer: Cracking	Lengths, widths and numbers of cracks produced in layer during operation or an accident	M	6	H	5	H	1
Outer PyC Layer: Chemical attack by water – Kinetics	Rate of reaction per unit surface area as a function of temperature and partial pressure of steam	H	7	H	3	H	6
Outer PyC Layer: Chemical attack by water – Catalysis	Modification of the reaction rate by fission products or impurities	M	4	M	4	H	3
Outer PyC Layer: Chemical attack by water – Changes in chemical form of fission products	Changes in chemical form resulting from oxidizing or reducing fission products	H	7	H	4	H	5

Table 4-5 TRISO-Coated Particle Fuel Depressurization Accident with Water Ingress Summary PIRT (continued)

		INEEL		ORNL		SNL	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
Outer PyC Layer: Chemical attack by water – Changes in graphite properties	Changes in diffusivity, porosity, adsorptivity, etc.	M	6	L	1	H	3
Outer PyC Layer: Chemical attack by water – Holdup reversals	Release of graphite FP inventory	M	6	M	3	L	4
Outer PyC Layer: Chemical attack by water – Temperature distributions	Impact of graphite oxidation on temperature distribution through material	H	8	H	5	H	3
SiC Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	7	H	4	H	6
SiC Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	7	H	4	M	2
SiC Layer: Thermal deterioration/decomposition	Decline in the quality of the layer due to thermal loading	M	8	M	4	M	3
SiC Layer: Fission product corrosion	Attack of layer by fission products, e.g., Pd	M	7	M	7	L	3
SiC Layer: Heavy metal diffusion	Diffusion of heavy metals through the intact layer	L	3	L	5	M	2
SiC Layer: Layer oxidation	Uptake of oxygen by the layer through a chemical reaction	H	5	M	4	L	5
SiC Layer: Fission product release through undetected defects	Passage of fission products from the buffer region through regions in the SiC layer that fail during operation or an accident	M	5	M	7	H	1
SiC Layer: Fission product release through failures, e.g., cracking	Passage of fission products from the buffer region through regions in the SiC layer that fail during operation or an accident	H	7	H	4	H	4

Table 4-5 TRISO-Coated Particle Fuel Depressurization Accident with Water Ingress Summary PIRT (continued)

		INEEL		ORNL		SNL	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
SiC Layer: Thermodynamics of the SiC-fission product system	Chemical form of fission products including the effects of solubility, intermetallics, and chemical activity	H	7	H	7	M	2
SiC Layer: Sintering	Change of SiC microstructure as a function of temperature	L	2	L	7	L	6
SiC Layer: Chemical attack by water – Kinetics	Rate of reaction per unit surface area as a function of temperature and partial pressure of steam	H	6	M	1	H	1
SiC Layer: Chemical attack by water – Catalysis	Modification of the reaction rate by fission products or impurities	M	5	L	1	M	1
SiC Layer: Chemical attack by water – Changes in chemical form of fission products	Changes in chemical form resulting from oxidizing or reducing fission products	H	7	H	4	H	5
SiC Layer: Chemical attack by water – Changes in SiC properties	Changes in diffusivity, porosity, adsorptivity, etc.	M	2	M	1	H	1
SiC Layer: Chemical attack by water – Holdup reversals	Release of graphite FP inventory	M	6	L	3	L	1
SiC Layer: Chemical attack by water – Temperature distributions	Impact of graphite oxidation on temperature distribution through material	H	8	H	5	H	5
Inner PyC Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	M	6	H	4	H	6
Inner PyC Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	M	6	M	4	M	2
Inner PyC Layer: Pressure loading (Fission products)	Stress loading of the layer by increased pressure from fission products	H	8	H	7	L	2

Table 4-5 TRISO-Coated Particle Fuel Depressurization Accident with Water Ingress Summary PIRT (continued)

		INEEL		ORNL		SNL	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
Inner PyC Layer: Pressure loading (Carbon monoxide)	Stress loading of the layer by carbon monoxide by increased pressure	H UO_2 L UCO	8	H	7	H	2
Inner PyC Layer: Layer oxidation	Reaction of pyrolytic graphite with oxygen released from the kernel	H	3	H	3	H	2
Inner PyC Layer: Stress state (compression/tension)	The state of the forces induced by external forces that are acting across the layer to resist movement	L	8	H	7	L	2
Inner PyC Layer: Cracking	Lengths, widths and numbers of cracks produced in layer during accident	H	5	H	4	H	1
Inner PyC Layer: Intercalation	Trapping of species between sheets of the graphite structure	M	6	L	2	M	2
Inner PyC Layer: Chemical attack by water – Kinetics	Rate of reaction per unit surface area as a function of temperature and partial pressure of steam	H	7	H	3	H	6
Inner PyC Layer: Chemical attack by water – Catalysis	Modification of the reaction rate by fission products or impurities	M	4	M	4	H	3
Inner PyC Layer: Chemical attack by water – Changes in chemical form of fission products	Changes in chemical form resulting from oxidizing or reducing fission products	H	7	H	4	H	5
Inner PyC Layer: Chemical attack by water – Changes in graphite properties	Changes in diffusivity, porosity, adsorptivity, etc.	M	6	L	1	H	3
Inner PyC Layer: Chemical attack by water – Holdup reversals	Release of graphite FP inventory	M	6	L	3	L	4
Inner PyC Layer: Chemical attack by water – Temperature distributions	Impact of graphite oxidation on temperature distribution through material	H	8	H	5	H	3

Table 4-5 TRISO-Coated Particle Fuel Depressurization Accident with Water Ingress Summary PIRT (continued)

		INEEL		ORNL		SNL	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
Buffer Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	L	7	H	7	H	4
Buffer Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	L	7	H	7	L	1
Buffer Layer: Response to kernel swelling	Mechanical reaction of the layer to the growth of the kernel via swelling	M	4	M	7	M	4
Buffer Layer: Maximum fuel gaseous fission product uptake	Maximum loading of fission products that can deposit from the gas phase onto surfaces of materials surrounding the fuel kernel	L	2	H	7	L	3
Buffer Layer: Layer oxidation	Reaction of buffer layer with oxide materials in the kernel	H	5	L	7	H	2
Buffer Layer: Thermal gradient	Change in temperature with distance	L	6	L	7	H	4
Buffer Layer: Irradiation and thermal shrinkage	Dimension changes in the buffer layer or changes in its porosity produced by irradiation or by exposure to elevated temperatures	M	7	M	6	L	5
Buffer Layer: Chemical attack by water – Kinetics	Rate of reaction per unit surface area as a function of temperature and partial pressure of steam	M	7	M	4	L	6
Buffer Layer: Chemical attack by water – Catalysis	Modification of the reaction rate by fission products or impurities	L	3	L	4	L	4
Buffer Layer: Chemical attack by water – Changes in chemical form of fission products	Changes in chemical form resulting from oxidizing or reducing fission products	H	7	H	4	M	3

Table 4-5 TRISO-Coated Particle Fuel Depressurization Accident with Water Ingress Summary PIRT (continued)

		INEEL		ORNL		SNL	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
Inner PyC Layer: Chemical attack by water – Changes in graphite properties	Changes in diffusivity, porosity, adsorptivity, etc.	L	3	L	1	L	3
Buffer Layer: Chemical attack by water – Holdup reversals	Release of graphite FP inventory	L	3	L	4	L	4
Buffer Layer: Chemical attack by water – Temperature distributions	Impact of graphite oxidation on temperature distribution through material	M	8	M	5	M	3
Kernel: Maximum fuel temperature	Maximum fuel temperature attained by the fuel kernel during the accident	H	7	H	7	H	6
Kernel: Temperature vs. time transient conditions	The time-dependent variation of fuel temperature with time	H	7	H	7	H	4
Kernel: Energy Transport: Conduction within kernel	Flow of heat within a medium from a region of high temperature to a region of low temperature	M	6	M	7	M	3
Kernel: Thermodynamic state of fission products	Chemical and physical state of fission products	H	7	H	4	H	5
Kernel: Oxygen flux	Mass transport of oxygen per unit surface area per unit time	L	6	L	3	M	3
Kernel: Grain growth	Enlargement of grains as a result of diffusion	L	4	L	3	L	8
Kernel: Buffer carbon-kernel interaction	Chemical reaction between carbon and the fuel (UO2) to form UC2 and CO (gas)	H	6	L	5	H	3
Kernel: Chemical attack by water – Kinetics	Rate of reaction per unit surface area as a function of temperature and partial pressure of steam	H	7	H	4	L	8
Kernel: Chemical attack by water – Catalysis	Modification of the reaction rate by fission products or impurities	M	5	M	1	L	8

Table 4-5 TRISO-Coated Particle Fuel Depressurization Accident with Water Ingress Summary PIRT (continued)

		INEEL		ORNL		SNL	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
Kernel: Chemical attack by water – Changes in chemical form of fission products	Changes in chemical form resulting from oxidizing or reducing fission products	H	7	H	4	L	8
Kernel: Chemical attack by water – Changes in kernel properties	Changes in diffusivity, porosity, adsorptivity, etc.	M	5	H	5	No Entry	No entry

- KL = Knowledge Level

Table 4-6 TRISO-Coated Particle Fuel Depressurization Accident with Air Ingress Summary PIRT

		INEEL		ORNL		SNL	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
Fuel Element: Irradiation history	The temperature, burnup and fast fluence history of the layer	M	7	H	7	H	3
Fuel Element: Condensed phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	6	H	4	M	1
Fuel Element: Gas phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure). Other factors include holdup, cracking, adsorption, site poisoning, permeability, sintering, and annealing	H	5	H	7	H	4
Fuel Element: Transport of metallic FPs through fuel element – Chemical form	Chemical stoichiometry of the chemical species that includes the radioisotope of interest	H	7	H	5	H	4
Fuel Element: Chemical attack by air – Kinetics	Rate of reaction per unit surface area as a function of temperature and partial pressure of air	H	7	H	5	H	4
Fuel Element: Chemical attack by air – Catalysis	Modification of the reaction rate by fission products or impurities	M	5	H	4	H	5
Fuel Element: Chemical attack by air – Changes in chemical form of fission products	Changes in chemical form resulting from oxidizing or reducing fission products	H	6	H	4	H	4
Fuel Element: Chemical attack by air – Changes in graphite properties	Changes in diffusivity, porosity, adsorptivity, etc.	H	6	H	4	H	2
Fuel Element: Chemical attack by air – Holdup reversals	Release of graphite FP inventory	M	6	H	4	L	5

Table 4-6 TRISO-Coated Particle Fuel Depressurization Accident with Air Ingress Summary PIRT (continued)

		INEEL		ORNL		SNL	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
Fuel Element: Chemical attack by air – Temperature distributions	Impact of graphite oxidation on temperature distribution through material	H	8	H	4	H	6
Outer PyC Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	6	H	5	H	6
Outer PyC Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	6	H	7	M	2
Outer PyC Layer: Layer oxidation	Uptake of oxygen by the layer through a chemical reaction	H	7	H	4	H	2
Outer PyC Layer: Stress state (compression/tension)	The state of the forces induced by external forces that are acting across the layer to resist movement	L	8	M	6	L	2
Outer PyC Layer: Intercalation	Trapping of species between sheets of the graphite structure	M	4	L	2	L	2
Outer PyC Layer: Trapping	Adsorption of fission products on defects	M	4	L	3	L	2
Outer PyC Layer: Cracking	Lengths, widths and numbers of cracks produced in layer during operation or an accident	M	6	H	5	H	1
Outer PyC Layer: Chemical attack by air – Kinetics	Modification of the reaction rate by fission products or impurities	H	7	H	4	H	2
Outer PyC Layer: Chemical attack by air – Catalysis	Modification of the reaction rate by fission products or impurities	M	4	M	3	H	4
Outer PyC Layer: Chemical attack by air – Changes in chemical form of fission products	Changes in chemical form resulting from oxidizing or reducing fission products	H	7	H	4	H	5
Outer PyC Layer: Chemical attack by air – Changes in graphite properties	Changes in diffusivity, porosity, adsorptivity, etc.	M	6	M	1	H	3

Table 4-6 TRISO-Coated Particle Fuel Depressurization Accident with Air Ingress Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL*	Rank	KL	Rank	KL
Outer PyC Layer: Chemical attack by air – Holdup reversal	Release of graphite FP inventory	M	6	L	3	L	4
Outer PyC Layer: Chemical attack by air – Temperature distributions	Impact of graphite oxidation on temperature distribution through material	H	8	H	5	H	3
SiC Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	7	H	4	H	6
SiC Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	H	7	H	4	M	2
SiC Layer: Thermal deterioration/decomposition	Decline in the quality of the layer due to thermal loading	M	8	H	4	M	3
SiC Layer: Fission product corrosion	Attack of layer by fission products, e.g., Pd	M	7	H	7	L	3
SiC Layer: Heavy metal diffusion	Diffusion of heavy metals through the intact layer	L	3	L	5	M	2
SiC Layer: Layer oxidation	Uptake of oxygen by the layer through a chemical reaction	H	5	H	4	L	5
SiC Layer: Fission product release through undetected defects	Passage of fission products from the buffer region through regions in the SiC layer that fail during operation or an accident	M	5	M	7	H	1
SiC Layer: Fission product release through failures, e.g., cracking	Passage of fission products from the buffer region through regions in the SiC layer that fail during operation or an accident	H	7	H	4	H	4
SiC Layer: Thermodynamics of the SiC-fission product system	Chemical form of fission products including the effects of solubility, intermetallics, and chemical activity	H	7	H	7	M	2

Table 4-6 TRISO-Coated Particle Fuel Depressurization Accident with Air Ingress Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL*	Rank	KL	Rank	KL
SiC Layer: Sintering	Change of SiC microstructure as a function of temperature	L	2	L	7	L	6
SiC Layer: Chemical attack by air – Kinetics	Modification of the reaction rate by fission products or impurities	H	5	H	4	H	4
SiC Layer: Chemical attack by air – Catalysis	Modification of the reaction rate by fission products or impurities	M	5	L	1	L	2
SiC Layer: Chemical attack by air – Changes in chemical form of fission products	Changes in chemical form resulting from oxidizing or reducing fission products	H	7	H	4	H	6
SiC Layer: Chemical attack by air – Changes in SiC properties	Changes in diffusivity, porosity, adsorptivity, etc.	M	4	H	1	M	2
SiC Layer: Chemical attack by air – Holdup reversal	Release of graphite FP inventory	M	4	L	3	L	1
SiC Layer: Chemical attack by air – Temperature distributions	Impact of graphite oxidation on temperature distribution through material	H	8	H	5	H	6
Inner PyC Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	H	6	H	4	H	6
Inner PyC Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	M	6	M	4	M	2
Inner PyC Layer: Pressure loading (Fission products)	Stress loading of the layer by increased pressure from fission products	H	8	H	7	L	2
Inner PyC Layer: Pressure loading (Carbon monoxide)	Stress loading of the layer by carbon monoxide by increased pressure	H UO_2 L UCO	8	H	7	L	2

Table 4-6 TRISO-Coated Particle Fuel Depressurization Accident with Air Ingress Summary PIRT (continued)

Factor, Characteristic, or Phenomenon	Definition	INEEL		ORNL		SNL	
		Rank	KL*	Rank	KL	Rank	KL
Inner PyC Layer: Layer oxidation	Reaction of pyrolytic graphite with oxygen released from the kernel	H	3	H	3	H	2
Inner PyC Layer: Stress state (compression/tension)	The state of the forces induced by external forces that are acting across the layer to resist movement	L	8	H	7	L	2
Inner PyC Layer: Cracking	Lengths, widths and numbers of cracks produced in layer during accident	H	5	H	4	H	1
Inner PyC Layer: Intercalation	Trapping of species between sheets of the graphite structure	M	6	L	2	M	2
Inner PyC Layer: Chemical attack by air – Kinetics	Modification of the reaction rate by fission products or impurities	H	7	H	4	H	5
Inner PyC Layer: Chemical attack by air – Catalysis	Modification of the reaction rate by fission products or impurities	M	4	M	1	H	3
Inner PyC Layer: Chemical attack by air – Changes in chemical form of fission products	Changes in chemical form resulting from oxidizing or reducing fission products	H	7	H	4	H	5
Inner PyC Layer: Chemical attack by air – Changes in graphite properties	Changes in diffusivity, porosity, adsorptivity, etc.	M	6	M	2	H	1
Inner PyC Layer: Chemical attack by air – Holdup reversal	Release of graphite FP inventory	M	6	L	2	L	2
Inner PyC Layer: Chemical attack by air – Temperature distributions	Impact of graphite oxidation on temperature distribution through material	H	8	H	4	H	3
Buffer Layer: Gas-phase diffusion	Diffusion of gaseous fission products through layer (Knudsen and bulk diffusion through pore structure, and pressure driven permeation through structure)	L	7	H	7	H	4
Buffer Layer: Condensed-phase diffusion	Inter-granular diffusion and/or intra-grannular solid-state diffusion	L	7	H	7	L	1

Table 4-6 TRISO-Coated Particle Fuel Depressurization Accident with Air Ingress Summary PIRT (continued)

		INEEL		ORNL		SNL	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
Buffer Layer: Response to kernel swelling	Mechanical reaction of the layer to the growth of the kernel via swelling	M	4	H	5	M	4
Buffer Layer: Maximum fuel gaseous fission product uptake	Maximum loading of fission products that can deposit from the gas phase onto surfaces of materials surrounding the fuel kernel	L	2	H	7	L	3
Buffer Layer: Layer oxidation	Reaction of buffer layer with oxide materials in the kernel	H	5	L	7	H	2
Buffer Layer: Thermal gradient	Change in temperature with distance	L	6	L	7	H	4
Buffer Layer: Irradiation and thermal shrinkage	Dimension changes in the buffer layer or changes in its porosity produced by irradiation or by exposure to elevated temperatures	M	7	M	6	L	5
Buffer Layer: Chemical attack by air – Kinetics	Modification of the reaction rate by fission products or impurities	M	7	M	3	L	2
Buffer Layer: Chemical attack by air – Catalysis	Modification of the reaction rate by fission products or impurities	L	3	M	1	L	4
Buffer Layer: Chemical attack by air – Changes in chemical form of fission products	Changes in chemical form resulting from oxidizing or reducing fission products	H	7	H	4	L	6
Buffer Layer: Chemical attack by air – Changes in graphite properties	Changes in diffusivity, porosity, adsorptivity, etc.	L	3	L	2	L	3
Buffer Layer: Chemical attack by air – Holdup reversal	Release of graphite FP inventory	L	3	L	2	L	2
Buffer Layer: Chemical attack by air – Temperature distributions	Impact of graphite oxidation on temperature distribution through material	H	8	H	4	M	4

Table 4-6 TRISO-Coated Particle Fuel Depressurization Accident with Air Ingress Summary PIRT (continued)

		INEEL		ORNL		SNL	
Factor, Characteristic, or Phenomenon	**Definition**	**Rank**	**KL***	**Rank**	**KL**	**Rank**	**KL**
Kernel: Maximum fuel temperature	Maximum fuel temperature attained by the fuel kernel during the accident	H	7	H	7	H	6
Kernel: Temperature vs. time transient conditions	The time-dependent variation of fuel temperature with time	H	7	H	7	H	4
Kernel: Energy Transport: Conduction within kernel	Flow of heat within a medium from a region of high temperature to a region of low temperature	M	6	M	7	M	3
Kernel: Thermodynamic state of fission products	Chemical and physical state of fission products	H	7	H	4	H	5
Kernel: Oxygen flux	Mass transport of oxygen per unit surface area per unit time	L	6	L	3	M	3
Kernel: Grain growth	Enlargement of grains as a result of diffusion	L	4	L	3	L	8
Kernel: Buffer carbon-kernel interaction	Chemical reaction between carbon and the fuel (UO2) to form UC2 and CO (gas)	H	6	L	5	H	3
Kernel: Chemical attack by air – Kinetics	Modification of the reaction rate by fission products or impurities	H	7 UO_2 6 UCO	H	3	L	9
Kernel: Chemical attack by air – Catalysis	Modification of the reaction rate by fission products or impurities	M	3	L	1	L	1
Kernel: Chemical attack by air – Changes in chemical form of fission products	Changes in chemical form resulting from oxidizing or reducing fission products	H	7	H	4	L	5
Kernel: Chemical attack by air – Changes in kernel properties	Changes in diffusivity, porosity, adsorptivity, etc.	M	5	M	4	L	8

- KL = Knowledge Level