19C CONTAINMENT EVENT TREES (CET) FOR CONTAINMENT PERFORMANCE SEQUENCES INITIATED DURING POWER OPERATION

Appendix 19C presents the containment events trees that delineate the severe accident progression given core damage events initiated during power operation. For each containment event tree, a summary of the top events and associated inputs are provided in the following tables and figures.

Table 19C-1—Containment Event Tree #CET CF - CET for Sequences Leading to Direct Containment Failure

Event-Tree Top Event		Input Events	Description of input events
#CET CF	Entry from CDES with containment overpressurized	#CET CF (Consequence)	Consequence is used to mark the transfer into this CET from the CDES link event trees.
#DUMMY		L2FLDUMMY (Basic event)	The input event is dummy event represented by a flag with numerical value of 1.0.

Table 19C-2—Containment Event Tree #CET ISL - CET for IS LOCA Sequences

Event-Tree Top Event		Input Events	Description of input events
#CET ISL	Input: from IS CDES tree	#CET-ISL (consequence)	Consequence is used to mark the transfer into this CET from the CDES link event trees.
#CET ISL LABEL	Label sequences for CET ISL	L2FLCET ISL	The input event is a flag with numerical value of 1.0.
#IS BL	IS LOCA break location is covered by water	Alt 1 - L2CP ISL BL WATER Alt 2 - L2CP ISL BL NO WATER	Events representing the presence or absence of an overlying pool of water for fission product scrubbing. (Event probabilities sum to 1.0)

Table 19C-3—Containment Event Tree #CET LIMITED CD - CET for Sequences Identified as Limited Core Damage Cases in CDES Link Trees

Event-Tree Top Event		Input Events	Description of Input Events
#CET LIMITED CD	Entry: sequences identified as limited CD in CDES link trees	#CET LIMITED CD (consequence)	Consequence is used to mark the transfer into this CET from the CDES link event trees.
#CET LIMITED CD LABEL	Label sequences for CET LIMITED CD	L2FLCET LIMITED CD (Basic event)	The input event is a flag with numerical value of 1.0.
#T1 CI	Containment isolated	Alt 1 – GL2 CONT ISOL3+ Alt 2 – GL2 CONT ISOL3- Alt 3 - GL2 CONT ISOL SUC (All fault tree top gates)	Inputs are described in #CET LO PRESSURE DESCRIPTION.

Table 19C-4—Containment Event Tree #CET LO PRESSURE - CET for Low Pressure CDES or Depressurized HI CDES
Sheet 1 of 6

Event-Tree Top Event		Input Events	Description of input events
#CET LO PRESSURE	ENTRY: Low pressure CDES or Depressurized HI CDES	#CET LO PRESSURE (consequence)	Consequence is used to mark the transfer into this CET from the CDES link event trees or from #CET1 HI PRESSURE (which also transfers here).
#CET LO PRESS LABEL	Label sequences for CET LO PRESS	Alt 1 - L2FLDELETE Alt 2 - L2FLCET LO PRESSURE	The input events are flags. L2FLDELETE has a value of zero (marks sequences which are not used). L2FLCET LO PRESSURE has a value of 1.0, it is used to mark sequences passing thru this CET.
#T1 CI	Containment isolated	Alt 1 – GL2 CONT ISOL3+ Alt 2 – GL2 CONT ISOL3- Alt 3 - GL2 CONT ISOL SUC (All fault tree top gates)	GL2 CONT ISOL3+ represents failures leading to a loss of containment isolation of 3" or greater diameter. GL2 CONT ISOL3- represents failures leading to a loss of containment isolation of less than 3" diameter. GL2 CONT ISOL SUC implements a delete term for the success path. Delete terms are added automatically by the PRA software for two branch event tree nodes, but the user has to implement these manually on three branch nodes.
#T1 CF	No cont. fail before vessel breach	Alt 2 - GL2 TF1 VEARLY CF(L) (Fault tree top gate)	Fault tree model for very early containment failure due to hydrogen combustion. Alt 2 is used as the input on the low pressure CET (Alt 1 is used in the high pressure CET).
#T2 CFIVSE	No cont fail due to in-vessel steam explosion	GL2 TF1 STM EXP-1 (Fault tree top gate)	Fault tree modeling containment failure due to in-vessel steam explosion. Dependency on CDES category and depressurization status (high pressure versus low pressure sequence) is addressed by the use of logic within the fault tree.

Table 19C-4—Containment Event Tree #CET LO PRESSURE - CET for Low Pressure CDES or Depressurized HI CDES
Sheet 2 of 6

Event-Tree Top Event		Input Events	Description of input events
#T2 PFIVSE	No reactor pit damage due to lower head failure by in-vessel steam explosion	GL2 TF2 STM EXP2-1 (Fault tree top gate)	Fault tree modeling failure of the lower head by a steam explosion which is assumed to lead to reactor pit damage. Dependency on CDES category and depressurization status (high pressure versus low pressure sequence) is addressed by the use of logic within the fault tree.
#T2 VB	Melt retention in-vessel	Alt 1 - GL2 TF2 VB-1 Alt 2 - GL2 TF2 VB=N (Fault tree top gates)	The Alt 1 fault tree input is used on the failure path. This fault tree represents the availability of LHSI to provide injection and the operator actions required to manually actuate LHSI. Phenomenological failure is also modeled in the fault tree using the failure probabilities derived from the Phenomenological Evalution. The Alt 2 fault tree is used on the success path for this event. Since the probability of failure at this node is relatively high (>0.05) it is necessary to manually add a quantitative assessment of the success probability. The fault tree uses the numerical complement of the in-vessel recovery failure probabilities. Both branches set the Boundary Condition Set IE+0-5H at this point in the event tree. This Boundary Condition Set activates house events which allow the recovery of Loss of Offsite Power to be considered in this timeframe (recovery between 2 hours and 7 hours) with the appropriate probabilities as assessed for the PRA.

Table 19C-4—Containment Event Tree #CET LO PRESSURE - CET for Low Pressure CDES or Depressurized HI CDES
Sheet 3 of 6

Event-Tree Top Event		Input Events	Description of input events
#T2 PFXVSE	Reactor Pit not damaged by ex-vessel steam explosion or (for hi press seqs) pit overpressure at VF	GL2 TF2 STM EXP EXV (Fault tree top gate)	A single fault tree is used for the low pressure CET and for the high pressure CET. Logic is set up within the fault tree to add in the pit overpressure failures which are applicable only for high pressure vessel failures. A single bounding event is used in both cases for the probability of steam explosion causing pit failure.
#T2 CF	No containment failure at the time of Vessel Breach	GL2 TF2 EARLYRUPT-1 (Fault tree top gate)	The same fault tree model is used in the high pressure and low pressure CETs. Logic is set up within the fault tree to select the relevant failures for low pressure and high pressure cases. DCH and rocketing are specific failure events for the high pressure vessel failure case. Failures due to hydrogen combustion are modeled in both CETs, with different probabilities.

Table 19C-4—Containment Event Tree #CET LO PRESSURE - CET for Low Pressure CDES or Depressurized HI CDES
Sheet 4 of 6

Event-Tree Top Event		Input Events	Description of input events
#T3 MSXV	Melt stabilization ex-vessel	Alt 1 - GL2 TF3 CCI Alt 2 - GL2 TF3 CCI 01 Alt 3 - GL2 TF3 CCI 01=N (Fault tree top gates)	The Alt 1 fault tree is used on pathways thru the CET where there has been no damage to the reactor pit, meaning that melt transfer to the spreading area will occur in an orderly manner, according to the design intent. This fault tree therefore models two failure paths: (i) a residual probability of phenomenological failure under normal circumstances, (ii) failure of the passive basemat flooding which leave the corium in dry conditions. Note that active SAHRS and SAHRS sprays are not required for melt stabilization success. This is because (as shown by MAAP analysis) if passive flooding is successful, dryout of the spreading area would not occur for over 72 hours. Furthermore, in the absence of active SAHRS/sprays and wet conditions in the spreading area, overpressure of the containment would occur before 72 hours, making MCCI irrelevant. The Alt 2 fault tree represents a guaranteed failure (100% probability of MCCI occurring). It is used on sequences where the pit was damaged by previous events on the sequence - it is conservatively assumed that any pit damage resulting in "bypass" of the reactor pit initial melt retention provision will prevent proper melt stabilization and lead to MCCI with a probability of 1.0. The Alt 3 input is used to model the success path when Alt 2 is used on the failure path. The fault tree consists of a single basic event with a probability of zero. This deletes all cutsets on this path and is used because the Alt 2 fault tree is a guaranteed failure.

Table 19C-4—Containment Event Tree #CET LO PRESSURE - CET for Low Pressure CDES or Depressurized HI CDES
Sheet 5 of 6

Event-Tree Top Event		Input Events	Description of input events
#T3 CFH2	No late containment failure due to hydrogen deflagration or FA or quench spiking	Alt 1 - GL2 TF3 CF H2-1 Alt 2 - GL2 TF3 CF H2 01-1 (Fault tree gates)	These fault trees model failure of the containment due to hydrogen combustion or a pressure peak during quenching of the corium ex-vessel (for some CDES). Logic is set up in the fault tree to select the correct hydrogen combustion failure probabilities for high and low pressure sequences and to apply the containment failure probability due to quench spiking only for CDES where it is applicable. The Alt 1 and Alt 2 variants are used on pathways with and without MCCI occurring. This influences the hydrogen combustion failure probabilities.
#T3 STMCNTL	Containment steam pressurization controlled	GL2 TF3 STM PCNTRL (Fault tree top gate)	This fault tree models the use of active SAHRS flooding and sprays to control the steam pressurization of the containment. Relevant operator actions are incorporated into the fault tree. Note that Boundary Condition Set IE+5-25H has been set beforehand to activate house events which allow the recovery of Loss of Offsite Power to be considered in the timeframe of this top event (recovery between 7 hours and 31 hours) with the appropriate probabilities as assessed for the PRA. AC power can therefore be available after LOOP initiators for the equipment modeled in the fault trees considered under this top event.

Table 19C-4—Containment Event Tree #CET LO PRESSURE - CET for Low Pressure CDES or Depressurized HI CDES
Sheet 6 of 6

Event-Tree Top Event		Input Events	Description of input events

#T3
LTCF=NO/OP/BMT
	Long term CF,
	Branches: 1 = No fail;
	2=OP fail due to non-condensibles;
	3=Basemat fail
		Alt 1 - L2PH LATE-CCI-CF=N
		Alt 2 - L2PH LATE-CCI-CF=OP
		Alt 3 - L2PH LATE-CCI-CF=BMT
		(Basic events)
			These events represent the probabilities of basemat melt thru, no failure and overpressure due to non-condensibles, as assessed in the phenomenological evaluation. The events sum to 1.0 and are only applied on pathways where MCCI is ongoing.

#T3 SPR	SAHRS sprays actuated to control source term	Alt 1 - GL2-TF3 SAHRS SPR ST Alt 2 - GL2 TF3 SAHRS SP(CI) (Fault tree top gates)	These fault trees represent failure of the sprays for source term mitigation (including operator failures). The Alt 1 event is used except following a loss of containment isolation has occurred, where the Alt 2 event is used. Different operator failure events are modeled in the two variant fault trees.

Table 19C-5—Containment Event Tree #CET SGTR - CET for SGTR Sequences

Event-Tree Top Event		Input Events	Description of input events
#CET SGTR	Entry: from SG CDES, sequences with FW not running	#CET SGTR (consequence)	Consequence is used to mark the transfer into this CET from the CDES link event trees.
#CET SGTR LABEL	Label sequences for CET SGTR	L2FLCET SGTR (Basic event)	Flag event, value = 1.0.

Table 19C-6—Containment Event Tree #CET SGTR FW - CET for SGTR Sequences, FW Running

Event-Tree Top Event		Input Events	Description of input events
#CET SGTR FW	CET for SGTR sequences, FW running	#CET SGTR FW (consequence)	Consequence is used to mark the transfer into this CET from the CDES link event trees.
#CET SGTR FW LABEL	Label sequences for CET SGTR FW	L2FLCET SGTR FW (Basic event)	Flag event, value = 1.0.

Table 19C-7—Containment Event Tree #CET1 HI PRESSURE - Initial CET for High Pressure CDES
Sheet 1 of 2

Event-Tree Top Event		Input Events	Description of input events
#CET1 HI PRESSURE	ENTRY: CD from a high pressure CDES	#CET1 HI PRESSURE (consequence)	Consequence is used to mark the transfer into this CET from the CDES link event trees.
#CET HI PRESSURE LBL	Label sequences for CET HI PRESSURE	Alt 1 - L2FLDELETE Alt 2 - L2FLCET1 HI PRESSURE (Basic events)	The input events are flag events. L2FLDELETE has a value of zero, and is used to delete cutsets on unused sequences. L2FLCET1 HI PRESSURE marks the cutsets as coming from this CET and has a value of 1.0.
#TF1-RCS.DEP	Depressurization before induced SGTR occurs	GL2 SYS DEPRESS-1 (Fault tree top gate)	This fault tree models the failure of the operator to depressurize the primary system according to cues in the EOPs (at 650 deg C core outlet temperature) or in the OSSA (cued by 1050 deg C in the core outlet). The failures modeled are hardware failures of the depressurization valves, operator failures and consequential failures arising from some initiating events.
#FW ANY SG	Feedwater (and heat removal) to any SG	GL2 SYS EFW 4/4 (Fault tree top event)	This fault tree models failure of feedwater and heat removal to all steam generators. If heat removal to any SG is available, challenge to the SG tubes is avoided and there will be no thermally induced SGTR.
#TF1-ISGTR	No induced SGTR	Alt 1 - GL2 TF1 ISGT=Y Alt 2 - GL2 TF1 ISGT=N (Fault tree top gates)	The Alt 1 fault tree models the induced SGTR probabilities as assessed in the phenomenological evaluation. Logic in the fault tree selects the correct values for the different CDES entering this CET. A fault tree model is also included as an input to this header to model stuck open steam generator valves causing depressurization of an SG, as this influences the induced SGTR probability. The Alt 2 fault tree is used to assign the appropriate probability to the success path at this node. It is required since the failure probabilities may be high in some cases. Selection logic is included to assign the correct probabilities according to the cases entering this node.

Table 19C-7—Containment Event Tree #CET1 HI PRESSURE - Initial CET for High Pressure CDES
Sheet 2 of 2

Event-Tree Top Event		Input Events	Description of input events
#TF1-IHLR	No Induced Hot Leg Rupture	Alt 1 - GL2 TF1 IHLR=N Alt 2 - GL2 TF1 IHLR=Y (Fault tree top gates)	The Alt 2 fault tree models the induced hot leg probabilities as assessed in the phenomenological evaluation. Logic in the fault tree selects the correct values for the different CDES entering this CET. The Alt 1 fault tree is used to assign the appropriate probability to the success path at this node. It is required since the failure probabilities may be high in some cases. Selection logic is included to assign the correct probabilities according to the cases entering this node.
#TF1-LOCADEP	RCS pressure remains high in small LOCA sequences	Alt 1 - L2PH LOCA-DEPRESS=N Alt 2 - L2PH LOCA-DEPRESS=Y (Basic events)	L2PH LOCA-DEPRESS=N is used to assign the probability of the pressure remaining high in Small LOCA sequences. Its value is set to 1.0; it is assumed that all incoming sequences remain at high pressure. L2PH LOCA-DEPRESS=Y takes a value of 0.0 - no depressurization is assumed.
#LBLDPR	Label according to reason for depressurization - HLR or Operator	Alt 1 - L2FLOP DEPRESS Alt 2 - L2FLHRL DEPRESS Alt 3 - L2FLANT DEPRESS (Basic events)	These events are flag events. They are used to mark cutsets with the mechanism of depressurization, as identified according to the event tree sequence. The flags are used for results interpretation.

Table 19C-8—Containment Event Tree #CET2 HI PRESSURE - CET for Low pressure CDES or Depressurized HI CDES
Sheet 1 of 3

Event-Tree Top Event		Input Events	Description of input events
#CET2 HI PRESSURE	Transfer CET - non-depressurized High Pressure CDES	#CET2 HI PRESSURE (consequence)	Consequence is used to mark the transfer into this CET from the CDES link event trees or from #CET1 HI PRESSURE which also transfers here.
#CET2 HI PRESS LABEL	Label sequences for CET2 HI PRESS	Alt 1 - L2FLDELETE Alt 2 - L2FLCET2 HI PRESSURE (Basic events)	The input events are flag events. L2FLDELETE has a value of zero, and is used to delete cutsets on unused sequences. L2FLCET2 HI PRESSURE marks the cutsets as coming from this CET and has a value of 1.0.
#T1 CI	Containment isolated	Alt 1 – GL2 CONT ISOL3+ Alt 2 – GL2 CONT ISOL3- Alt 3 - GL2 CONT ISOL SUC (All fault tree top gates)	As explained in Low Pressure CET description.
#T1 CF	No cont. fail before vessel breach	Alt 1 - GL2 TF1 VEARLY CF(H) (Fault tree top gate)	Fault tree model for very early containment failure due to hydrogen combustion. Alt 1 is used as the input on the high pressure CET (Alt 2 is used in the low pressure CET).
#T2 CFIVSE	No cont fail due to in-vessel steam explosion	GL2 TF1 STM EXP-1 (Fault tree top gate)	As explained in Low Pressure CET description.
#T2 PFIVSE	No reactor pit damage due to lower head failure by in-vessel steam explosion	GL2 TF2 STM EXP2-1 (Fault tree top gate)	As explained in Low Pressure CET description.

Table 19C-8—Containment Event Tree #CET2 HI PRESSURE - CET for Low pressure CDES or Depressurized HI CDES
Sheet 2 of 3

Event-Tree Top Event		Input Events	Description of input events
#T2 PFXVSE	Reactor Pit not damaged by ex-vessel steam explosion or (for hi press seqs) pit overpressure at VF	GL2 TF2 STM EXP EXV (Fault tree top gate)	As explained in Low Pressure CET description.
#T2 CF	No containment failure at the time of Vessel Breach	GL2 TF2 EARLYRUPT-1 (Fault tree top gate)	As explained in Low Pressure CET description.
#T3 MSXV	Melt stabilization ex-vessel	Alt 1 - GL2 TF3 CCI Alt 2 - GL2 TF3 CCI 01 Alt 3 - GL2 TF3 CCI 01=N (Fault tree top gates)	As explained in Low Pressure CET description.
#T3 CFH2	No late containment failure due to hydrogen deflagration or FA or quench spiking	Alt 1 - GL2 TF3 CF H2-1 Alt 2 - GL2 TF3 CF H2 01-1 (Fault tree gates)	As explained in Low Pressure CET description.
#T3 STMCNTL	Containment steam pressurization controlled	GL2 TF3 STM PCNTRL (Fault tree top gate)	As explained in Low Pressure CET description.

Table 19C-8—Containment Event Tree #CET2 HI PRESSURE - CET for Low pressure CDES or Depressurized HI CDES
Sheet 3 of 3

Event-Tree Top Event		Input Events	Description of input events
#T3 LTCF=NO/OP/BMT	Long term CF, Branches: 1 = No fail; 2=OP fail due to non-condensibles; 3=Basemat fail	Alt 1 - L2PH LATE-CCI-CF=N Alt 2 - L2PH LATE-CCI-CF=OP Alt 3 - L2PH LATE-CCI-CF=BMT (Basic events)	As explained in Low Pressure CET description.
#T3 SPR	SAHRS sprays actuated to control source term	Alt 1 - GL2-TF3 SAHRS SPR ST Alt 2 - GL2 TF3 SAHRS SP(CI) (Fault tree top gates)	As explained in Low Pressure CET description.

Figure 19C-1—Containment Event Tree for CDES with Guaranteed Containment Failure

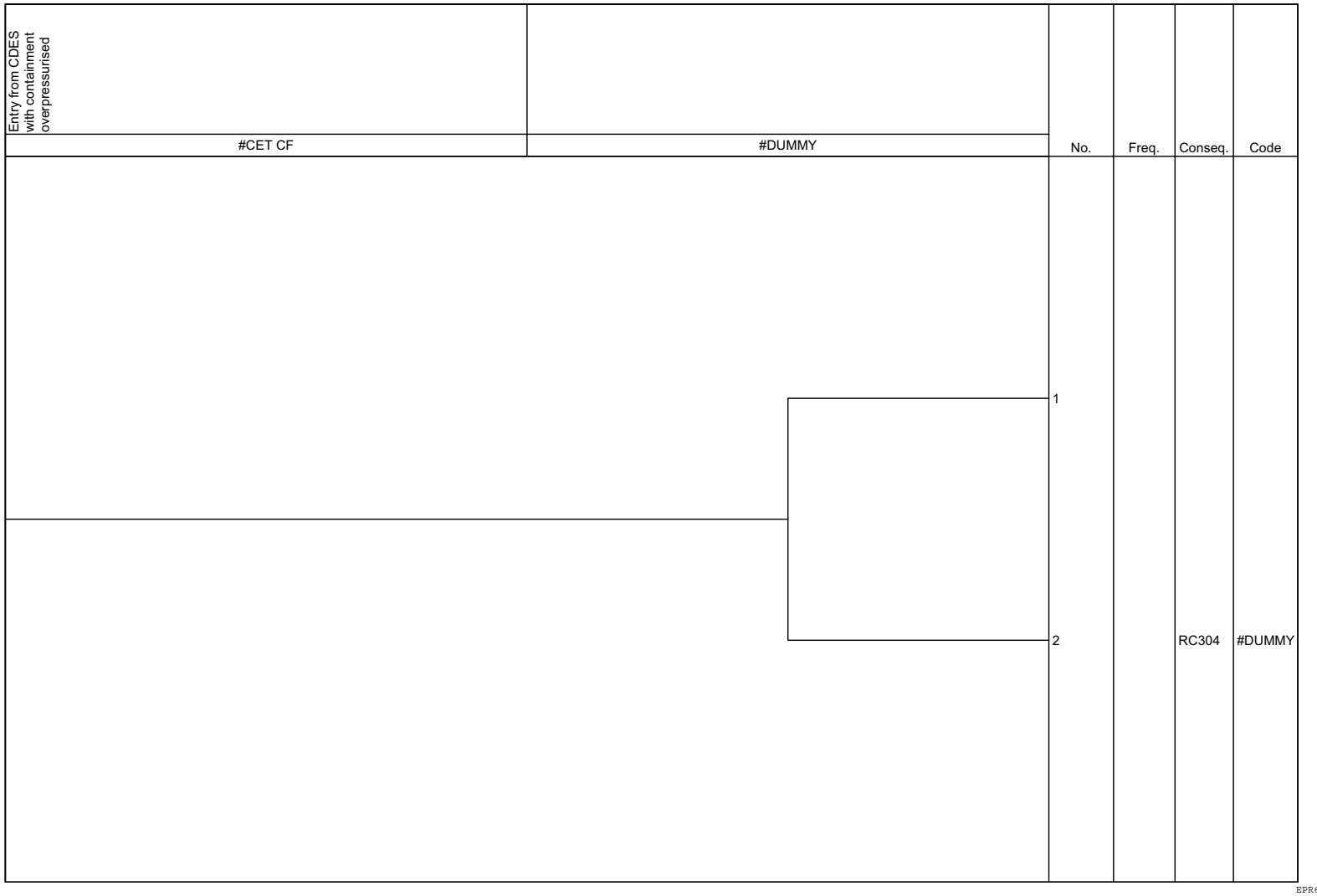

Figure 19C-2—Containment Event Tree for IS LOCA CDES

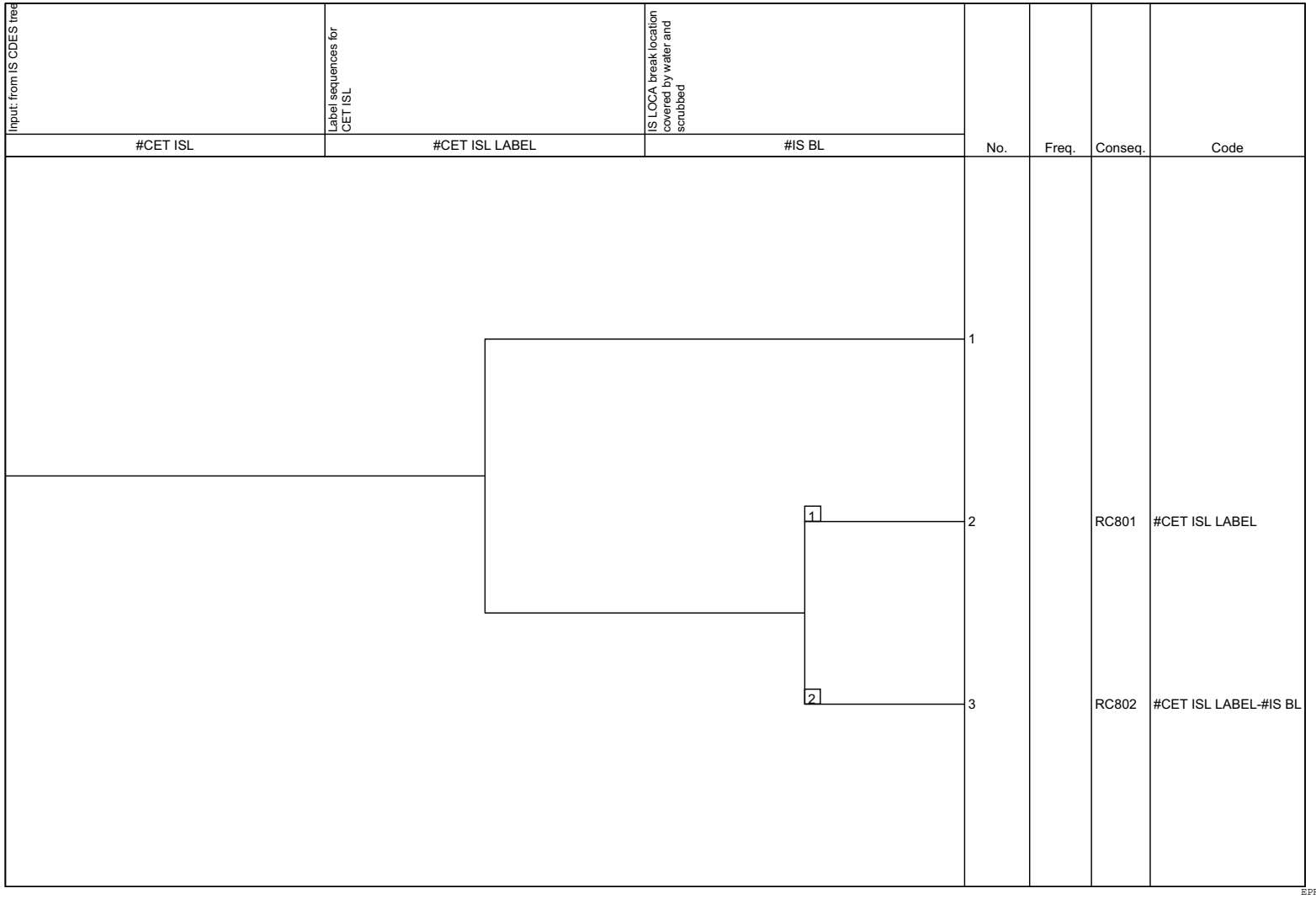

Figure 19C-3—Containment Event Tree for CDES Link Event Tree Sequences Resulting in Limited Core Damage

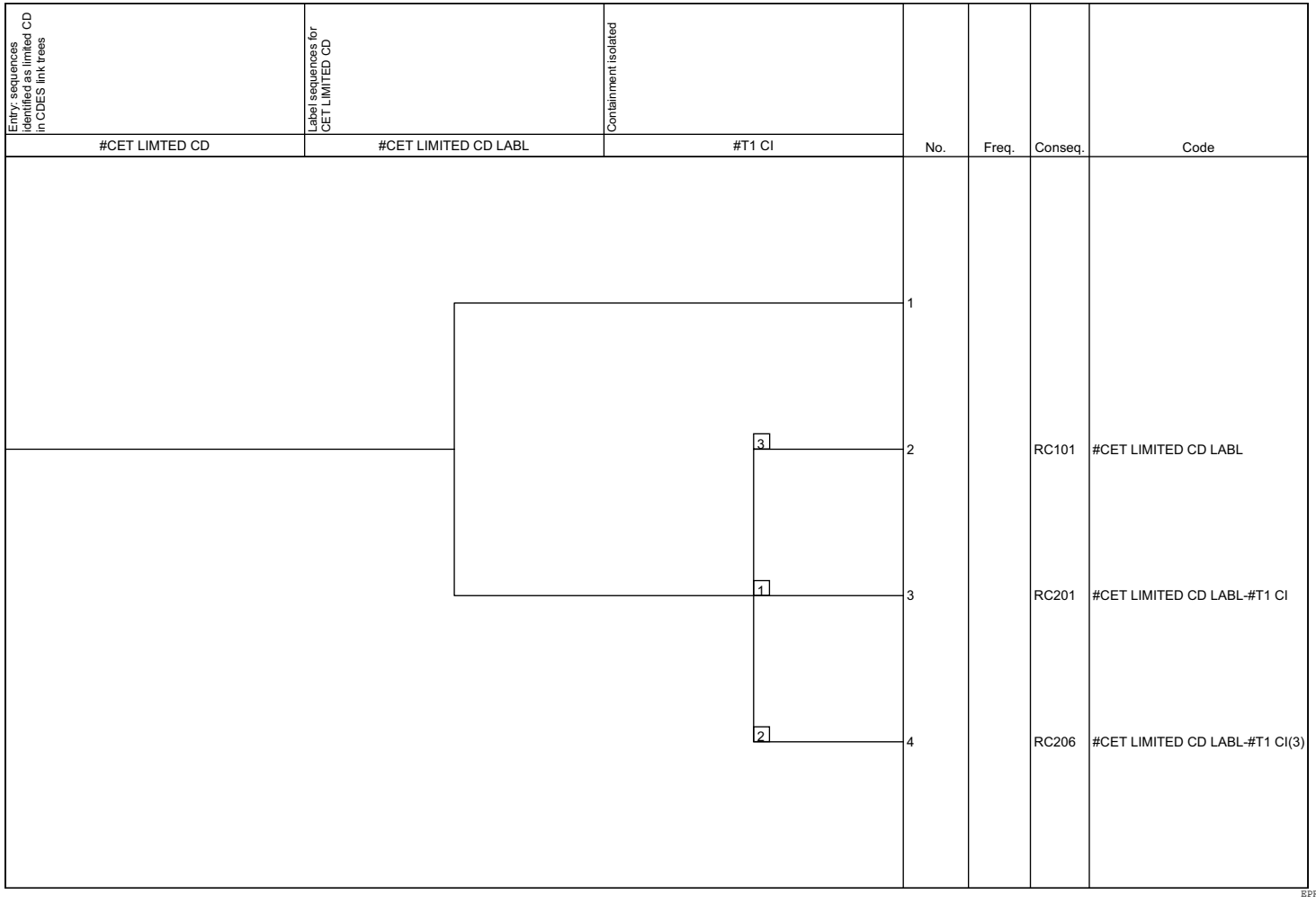

Figure 19C-4—Containment Event Tree for Low Pressure CDES or CDES which depressurizes in Stage 1 High Pressure CET

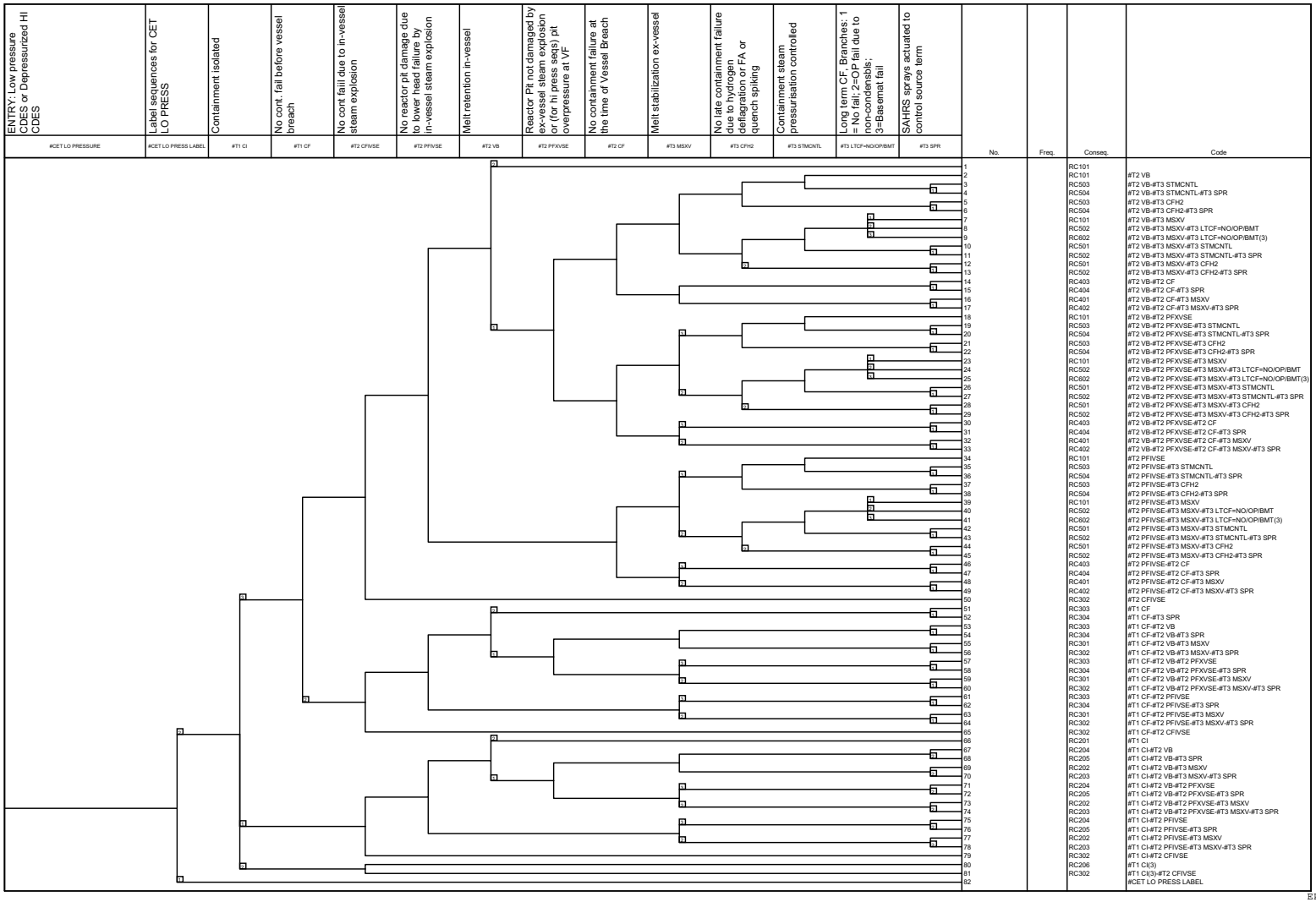

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Figure 19C-5—Containment Event Tree for Unscrubbed SGTR Sequences

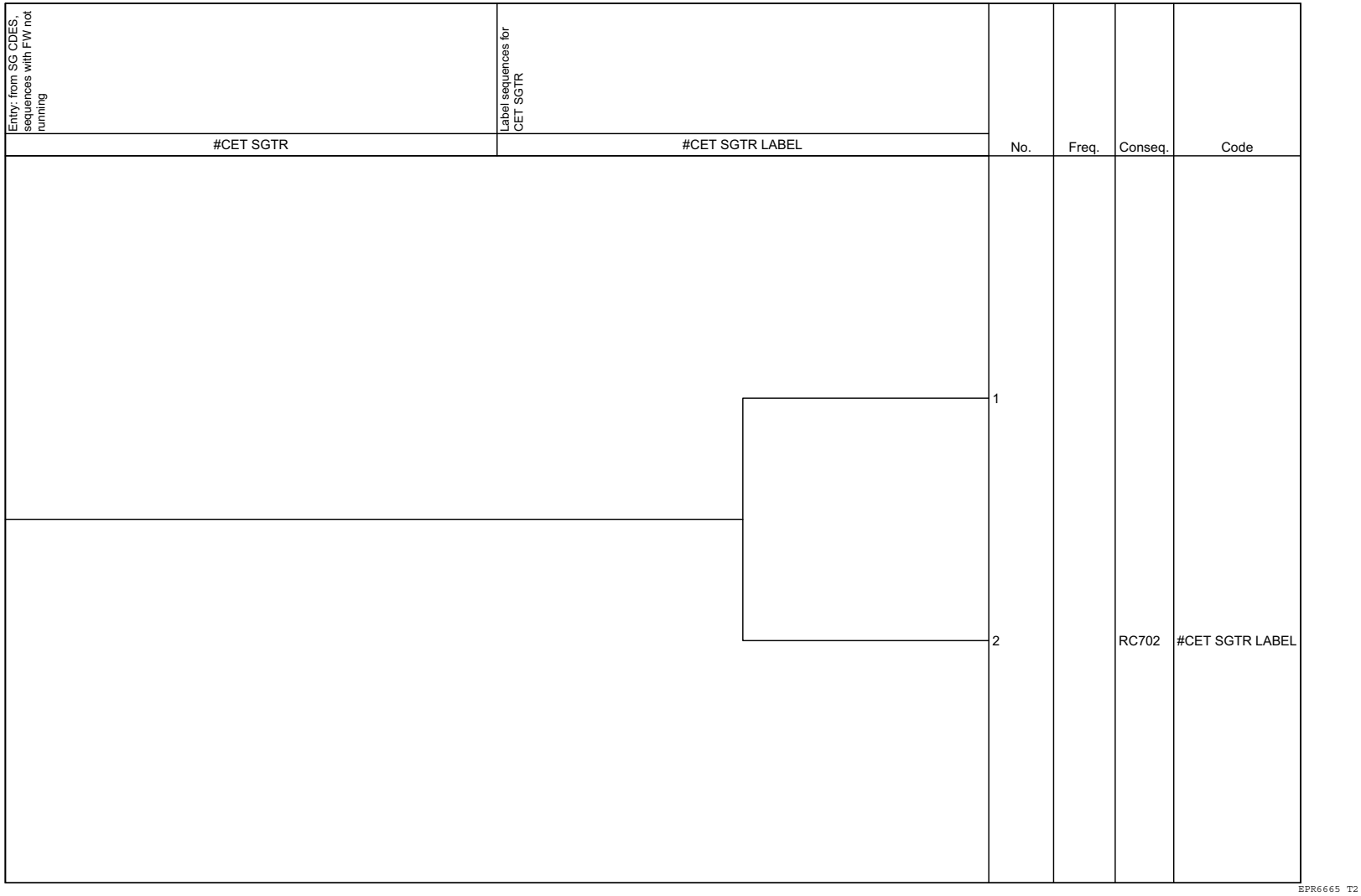

Figure 19C-6—Containment Event Tree for Scrubbed SGTR Sequences

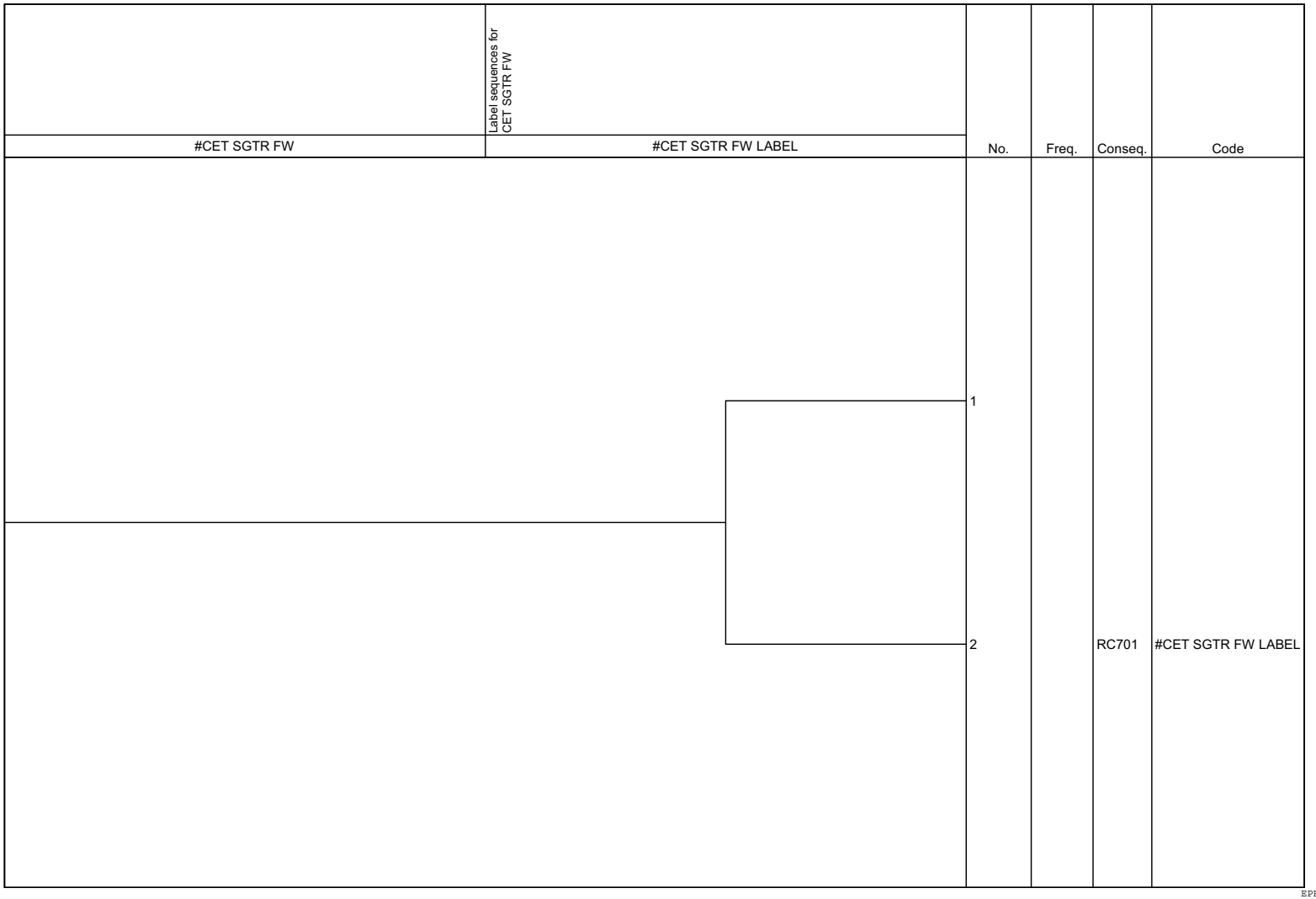

Figure 19C-7—First Stage Containment Event Tree for High Pressure CDES

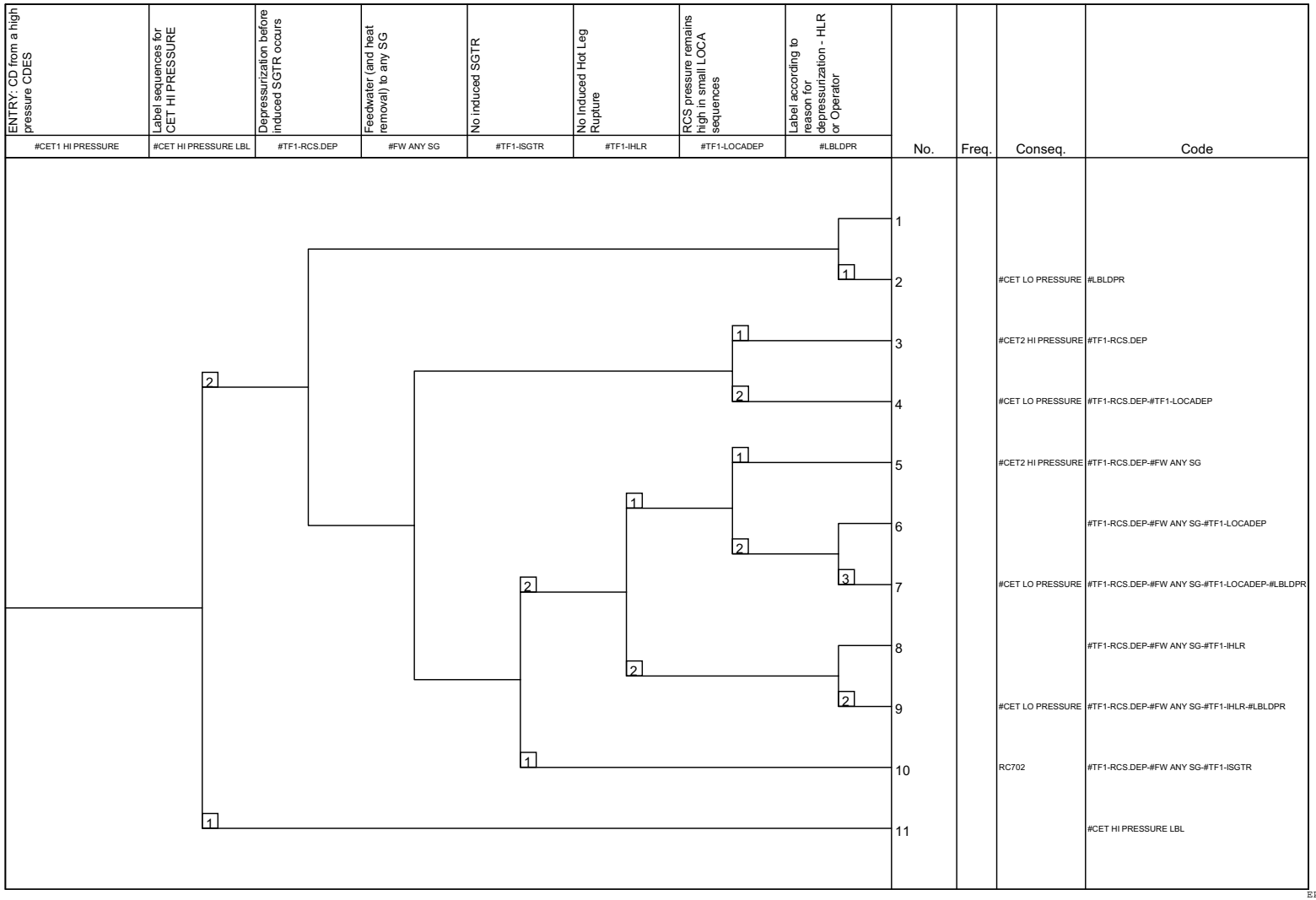

Figure 19C-8—Second Stage Containment Event Tree for CDES Remaining at High Pressure