

Function / Requirement	Potential failure mode	Potential effect of failure	SEV	Class	Current process controls			Action results			
					Potential cause	Occur	R.P.N.	Actions Taken	Sev	Occur	R.P.N.
Requirement 1: Beam Raster 2x2 mm (long term)	Raster power supply failure	<ul style="list-style-type: none"> > Cell temp hi > beam induced embrittlement > drill hole in cell > release of T2 from CL-1 > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem 	4		A/C power failure	4	4	<ul style="list-style-type: none"> > FSD on Power supply > FSD on comparator > Cell design with cooling give cell long life in these conditions > Check raster size at start/during run > Multilayer containment with controlled release 	1	2	0
			4		Hardware error	2	0	<ul style="list-style-type: none"> > FSD on Power supply > FSD on comparator > Cell design with cooling give cell long life in these conditions > Check raster size at start/during run > Multilayer containment with controlled release 	1	2	0
	Control system failure	<ul style="list-style-type: none"> > Cell temp hi > beam induced embrittlement > drill hole in cell > release of T2 from CL-1 > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem 	4		Operator error	3	4	<ul style="list-style-type: none"> > FSD on Power supply > FSD on comparator > Procedures and training > Cell design with cooling give cell long life in these conditions > Check raster size at start/during run > Multilayer containment with controlled release 	1	2	0
			4		Hardware error	2	3	<ul style="list-style-type: none"> > FSD on Power supply > FSD on comparator > Cell design with cooling give cell long life in these conditions > Check raster size at start/during run > Multilayer containment with controlled release 	1	2	0
			4		Software error	2	3	<ul style="list-style-type: none"> > FSD on Power supply > FSD on comparator > Cell design with cooling give cell long life in these conditions > Check raster size at start/during run > Multilayer containment with controlled release 	1	2	0
	Magnet failure	<ul style="list-style-type: none"> > Cell temp hi > beam induced embrittlement > drill hole in cell > release of T2 from CL-1 > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem 	4		Conductor failure	1	1	<ul style="list-style-type: none"> > FSD on Power supply > FSD on comparator > Cell design with cooling give cell long life in these conditions > Check raster size at start/during run > Multilayer containment with controlled release 	1	2	0
			4		structural failure	1	1	<ul style="list-style-type: none"> > FSD on Power supply > FSD on comparator > Cell design with cooling give cell long life in these conditions > Check raster size at start/during run > Multilayer containment with controlled release 	1	2	0
	Requirement 2: Target cell temp below 150K with beam on	ESR Failure	<ul style="list-style-type: none"> > Uncontrolled T2 release > Cell wall temp hi -> beam induced embrittlement > release of T2 from CL-1 > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem 	4		Power Failure	4	4	<ul style="list-style-type: none"> > Robust design simply warms up > FSD on over temp (redundant) > Multilayer containment with controlled release 	1	4
4					ESR equip fail	4	4	<ul style="list-style-type: none"> > Robust design simply warms up > FSD on over temp (redundant) > Multilayer containment with controlled release 	1	3	1
4					ESR operator fail	2	3	<ul style="list-style-type: none"> > Robust design simply warms up > FSD on over temp (redundant) > Procedures > Multilayer containment with controlled release 	1	1	0
Control system failure		<ul style="list-style-type: none"> > Uncontrolled T2 release > Cell wall temp hi -> beam induced embrittlement > release of T2 from CL-1 > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem 	4		Operator error	3	4	<ul style="list-style-type: none"> > Robust design simply warms up > FSD on over temp (redundant) > Procedures and training > Control has redundant hardware interlocks that do not require software > Multilayer containment with controlled release 	1	2	0
			4		Hardware failure	2	3	<ul style="list-style-type: none"> > Robust design simply warms up > FSD on over temp (redundant) > Procedures and training > Multilayer containment with controlled release > Control has redundant hardware interlocks that do not require software 	1	1	0
			4		software failure	2	3	<ul style="list-style-type: none"> > Robust design simply warms up > FSD on over temp (redundant) > Procedures and training > Control has redundant hardware interlocks that do not require software > Multilayer containment with controlled release 	1	1	0
Beam Overcurrent		<ul style="list-style-type: none"> > Uncontrolled T2 release > Cell wall temp hi -> beam induced embrittlement > release of T2 from CL-1 > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem 	4		Operator error	3	4	<ul style="list-style-type: none"> > Procedures and training > Software limits on slit opening > DB of limits for target position > Multilayer containment with controlled release 	3	2	2
			4		Hall CH crew failure	4	4	<ul style="list-style-type: none"> > Shift crew cannot override limits > Multilayer containment with controlled release 	3	0	0
Requirement 3: CL-1: containment level 1 holds 100% of T2	CASE:1 Catastrophic cell failure while in beam permit	<ul style="list-style-type: none"> > Uncontrolled T2 release > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem 	4		spontaneous failure	3	4	<ul style="list-style-type: none"> > Conservative design > No source of overpressure > Cell temp < 150K with beam > Selected alloy T2 compatible (@ T,P) > Multilayer containment with controlled release > T2 Monitor/alarm/exhaust systems 	3	1	1
			4		cell overpressure	3	4	<ul style="list-style-type: none"> > Conservative design > No source of overpressure > Cell temp < 150K with beam > Selected alloy T2 compatible (@ T,P) > Multilayer containment with controlled release > T2 Monitor/alarm/exhaust systems 	3	1	1
			4		beam induced failure	3	4	<ul style="list-style-type: none"> > See above (Beam raster and Target temp) 	3	1	1
			4		control system failure	3	4	<ul style="list-style-type: none"> > Conservative design > No source of overpressure > Cell temp < 150K with beam > Selected alloy T2 compatible (@ T,P) > Multilayer containment with controlled release > Hard stops on motion > T2 Monitor/alarm/exhaust systems 	3	1	1
			4		Impact load	4	4	<ul style="list-style-type: none"> > No auxiliary equipment in chamber > Hard stops on motion 	3	1	1
			4		See Case 1		0	<ul style="list-style-type: none"> See Case 1 			0
	Case 2: Catastrophic cell failure while in controlled access	<ul style="list-style-type: none"> > Uncontrolled T2 release > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem 	4		Puncture of scattering chamber and cell with foreign object	3	4	<ul style="list-style-type: none"> > Procedure to move target to HOME prior to access > Procedure to cover windows for heavy work near pivot > Multilayer containment with controlled release outer layer Hall A > Procedures for truck ramp protocols > T2 Monitor/alarm/exhaust systems 	3	1	1
			4		Crane/forklift/HEO accident	1	1	<ul style="list-style-type: none"> > Heavy work in Hall performed under procedures only by qualified/trained personnel > T2 Monitor/alarm/exhaust systems 	3	1	1
	Case 3: Catastrophic cell failure while in restricted access	<ul style="list-style-type: none"> > Uncontrolled T2 release > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem 	0		See case 2	0	0	<ul style="list-style-type: none"> > See Case 2 > Truck ramp protocols equiv controlled access 	0	0	0
	Case 4: Catastrophic cell failure while installing or removing cell	<ul style="list-style-type: none"> > Uncontrolled T2 release > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem > Injury from flying debris 	4		Dropped cell	4	4	<ul style="list-style-type: none"> > Conservative design with window covers > Procedures/training > PPE > Multilayer containment with active air prevents worker dose > T2 Monitor/alarm/exhaust systems 	3	1	1
			4		puncture with tool	4	4	<ul style="list-style-type: none"> > Conservative design with window covers > Procedures/training > PPE > Multilayer containment with active air prevents worker dose > T2 Monitor/alarm/exhaust systems 	3	1	1
			4		Procedural error	2	3	<ul style="list-style-type: none"> > Conservative design with window covers > Procedures/training > PPE > Multilayer containment with active air prevents worker dose > T2 Monitor/alarm/exhaust systems 	3	1	1
	Case 5: Catastrophic cell failure while shipping	<ul style="list-style-type: none"> > Uncontrolled T2 release > T2 contamination of Hall and beamline > Possible high dose to public over 10 mrem 	4		Severe impact load	2	3	<ul style="list-style-type: none"> > Triple layer containment > DOT procedures/requirements 	2	2	1
	Case 6: Catastrophic cell failure while filling/recovering T2	<ul style="list-style-type: none"> > Uncontrolled T2 release > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem > Injury from flying debris 	4		Operator error	4	4	<ul style="list-style-type: none"> > Relief system at 1000 psi > Design pressure with shipping covers meets 1000 psi > filled in glove box > Procedures/training > T2 Monitor/alarm/exhaust systems 	3	1	1
4				catastrophic cell failure	4	4	<ul style="list-style-type: none"> > Relief system at 1000 psi > Design pressure with shipping covers meets 1000 psi > filled in glove box > Procedures/training > T2 Monitor/alarm/exhaust systems 	3	1	1	

			4	Dropped/puncture cell	4	4	> Relief system at 1000 psi > Design pressure with shipping covers meets 1000 psi > filled in glove box > Procedures/training > T2 Monitor/alarm/exhaust systems	3	1	1
Requirement 4: CL-2: containment level 2 is maintained for controlled release	CASE:1 while in beam permit > vacuum failure > Pump exhaust to Hall A > Open to upstream beamline	> Failure to provide level 2 containment > Uncontrolled T2 release > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem	3	Pump vented to Hall		0	Pumps vented to exhaust system	2	1	0
			3	Beam steering error	4	4	> Collimators installed to prevent cell damage > Ion chamber FSD > T2 Monitor/alarm/exhaust systems	2	1	0
			3	Puncture	4	4	> No auxiliary equipment in chamber > Hard stops on motion > window covers on when working near pivot > Heavy work near pivot requires procedures > T2 Monitor/alarm/exhaust systems	2	1	0
				Always open to beamline	4	0	Isolation window	2	2	1
	Case 2: While in controlled access > vacuum failure > Pump exhaust to Hall A > Open to upstream beamline	> Failure to provide level 2 containment > Uncontrolled T2 release > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem	3	Always open to beamline	4	4	Isolation window	2	2	1
			3	Puncture	4	4	> No auxiliary equipment in chamber > Hard stops on motion > window covers on when working near pivot > Heavy work near pivot requires procedures > T2 Monitor/alarm/exhaust systems	2	2	1
			3	Pump vented to Hall	4	4	Pumps vented to exhaust system	2	2	1
	Case 3: Restricted Access > vacuum failure > Pump exhaust to Hall A > Open to upstream beamline	> Failure to provide level 2 containment > Uncontrolled T2 release > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem > truck ramp release possible	0	See Case 2	0	0	See Case 2	0	0	0
			4	Both ramp doors open	4	4	> Ramp protocols > Training/procedures	2	2	1
	Case 4: Installation/removal of cell	> Uncontrolled T2 release > T2 contamination of Hall and beamline > dose to worker > 1 rem > dose to public over 10 mrem > Injury from flying debris	4	Chamber must be open	4	4	> Handling Hut > Exhaust system connected to chamber Forced air to "contain T2" > Procedures for installation/removal and training > Hut+Exhaust give 2nd containment	2	1	0
	Case 5: Catastrophic cell failure while shipping	> Uncontrolled T2 release > T2 contamination of Hall and beamline > Possible high dose to public over 10 mrem	4	Severe impact load	2	3	Primary, secondary and tertiary containment designed for some impact loading	2	2	1
Requirement 4: CL-23 containment level 3 is maintained for controlled release Includes Hall A and Exhaust system	Hall A open	Possible T2 release up ramp and/or into labyrinth Uncontrolled release of T2	3	Door propped open	4	4	Procedures/training/signage/CANS activated	3	2	2
			3	Both ramp doors open	4	4	Procedures/training/signage/CANS activated Ramp Protocols	3	2	2
	Exhaust system failure	T2 trapped in Hall A and Leaking out Uncontrolled release of T2	3	Power failure	4	4	Backup Power	3	2	2
			3	Mech failure	2	2	Use smoke system	3	1	1
	Shipping container fails	> Uncontrolled T2 release > T2 contamination of Hall and beamline > Possible high dose to public over 10 mrem	4	Severe Impact	2	3	Primary, secondary and tertiary containment designed for some impact loading	2	2	1