Technical Progress, Remaining Work, and Risk Management

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NCSX has progressed from design and procurement to construction

- The design and procurement of the most difficult stellarator core components (VV subassemblies and modular coil winding forms) have been completed
- 12 of 18 modular coils have been wound and epoxy impregnated
- TF coil fabrication is underway at Everson Tesla
- Field period assembly is underway at PPPL
  - Assembly of the diagnostic loops, cooling tubes, thermocouples on the 1st VVSA is nearly complete and the 2nd is in progress
  - Development trials for assembling modular coil into a half-period assembly are nearly complete

Most major design risks and all major procurement risks have been retired

- Early risks were substantial
  - Resolution of key technical issues
    - Can industry cast and machine the winding forms?
    - Can industry form and weld together the VV panels to form the highly shaped VV?
    - Can we wind the coils using compacted cable conductor and maintain tolerances?
  - Satisfactory completion of VV, MC, and TF final design
  - Cost, schedule, and quality of major (VVSA and MCWF) procurements
  - Large uncertainties were associated with these efforts simply because we had never built a compact stellarator like NCSX before (and neither had our vendors)
- Risks were retired but the time and resources required exceeded the CD2 baseline
- The major remaining design risk is the design of the modular coil interface hardware with potential cost and schedule impacts for downstream assembly activities
- Task forces formed to coordinate efforts resolving high leverage design issues

Task force on modular coil interface design has made good progress pushing the design closer to completion

- Interface design in inboard unbolted region is the most critical issue
  - It is presently the critical path with potential to impact cost and schedule of downstream assembly activities
- Design options systematically evaluated against performance requirements and risks
- Task force identified the “welded shim” option as the best path forward for joining modular coils within a field period
  - Field errors from not having toroidal break near inboard midplane found acceptable
  - Welds appear structurally adequate
  - Main risk is weld distortion which is being aggressively pursued with R&D and consultation with welding experts outside the project, e.g. Edison Welding Institute
  - Plan to weld two bare winding forms together to demonstrate manageability of weld distortion
- Task force is pursuing an extension of the outboard bolted joints together with a low friction shim joining field periods
  - Must be an insulating joint and is not accessible near the midplane so welded shims are not applicable
  - Main risks are shear loads on the first bolted joint and durability of the low friction shim
  - Analysis of the shear loads is underway
  - Adapting the W7-X low friction, sliding surface design is being considered because it is already qualified for cryogenic service

Task force on assembly sequence

- Great strides made in defining assembly tasks and developing consensus on assembly approach
- Stakeholders involved include design engineers, dimensional control experts, and assembly engineers
- Assembly sequence plans have much more detail than before, considerably reducing the uncertainty in the scope of work to be performed
- Assembly sequence plans are complete
- Proposed baseline and risk assessment are consistent with completed assembly sequence plans

Task force on assembly tolerance requirements

- Concluded that 10 mil (0.25 mm) requirement assembling coils in a 3-pack could be modestly relaxed to improve prospects for getting coil alignment set with minimum number of iterations
- Assembly engineers concluded it would be best to work to the present 10 mil requirement which they deem manageable and save any the tolerance budget for downstream assembly operations
- No change in the overall assembly tolerance of +/- 60 mils (1.5 mm) was made

Progress on other risks and opportunities

- Aluminum was adopted in place of Inconel for TF/PF coil support structures
  - Field errors due to eddy currents appear acceptable
  - Cost estimate has been updated to reflect change
  - Substantial cost savings ($500K) realized relative to Inconel
- Assembly sleds used in final assembly not seen as a significant risk
  - The main technical risk is deflection under load
  - Performance to be tested using first field period
  - Ample time exists in the schedule between completion of the first and third periods to test and make modifications to the sleds to improve their stiffness if needed

Remaining risks are largely related to on-site assembly

- The character of remaining risks is different
  - The stellarator design is far more mature - we know what the parts look like and how they fit together
  - There are no high risk procurements left
  - The remaining work will largely be performed in-house (PPPL/ORNL) giving us direct control of resources
- ...but substantial risks remain (see risk register)

Risk management initiatives

- The risk management process
  - Identify risks and analyze likelihood and consequences
  - Develop and implement mitigation plans
  - Track progress resolving risks
- Risk management initiatives
  - Formalize work approval process - scope, basis of estimate and uncertainty, and risk assessment documented in an auditable manner
  - Record risks in a risk register which will be used to focus attention, prioritize resources, and track progress resolving risks
  - Incorporate probabilistic, risk-based cost and schedule contingencies in proposed baseline
  - Provide expanded, regular review of significant risks planned within the project and with the Director's Office

Risk identification and mitigation

- Formal work approval forms (WAFs) provide a more structured approach adopted for planning jobs and managing risk
  - Remaining scope (tasks and resources) defined and documented
  - Basis of estimate and uncertainty range documented
  - Job risks identified and appropriate mitigation plans implemented, i.e. incorporated in the project baseline as specific activities
  - Likelihood and consequences of risks assessed
  - WAFs approved by RLM, Project Manager, and Engineering Department Head
  - WAFs for all remaining jobs have been prepared
  - WAFs (including risk assessments) will be updated prior to jobs being opened and as part of change control process

Risk register

- All risks are recorded in a new risk register
  - Job managers responsible for identifying risks related to their jobs and documenting in WAFs
  - Project management responsible for identifying and mitigating global risks
  - Brainstorming sessions have been useful for stimulating risk identification
  - Systems Engineering is responsible for maintaining a comprehensive list of risks in the risk register
- Risk register features important improvements over the previous critical issues list
  - Likelihood and consequences of risks are tabulated - facilitates risk classification which aids in focusing management attention and project resources.
  - Cost and schedule impacts are quantified which aids in establishing risk-based contingency requirements
- The current risk register is provided in the Appendix

Risk classification

- Likelihood of risks range from non-credible (P~0) to very likely (P>0.8)
- Consequences range from negligible to crisis
- The risk classification matrix is used to classify risks as low, moderate, or high

			Risk Level Matrix				
Likelihood	Very Likely	VL	Low	Moderate	High	High	High
	Likely	L	Low	Moderate	Moderate	High	High
	Unlikely	U	Low	Low	Moderate	Moderate	High
	Very Unlikely	VU	Low	Low	Low	Moderate	High
	Non-credible	NC	Low	Low	Low	Low	Low
			Negligible	Marginal	Significant	Critical	Crisis
			Consequence				

A fresh looks at risks prompted new mitigating actions

- Additional "back office" support budgeted to keep it from becoming a chronic bottleneck
- Need for special reviews prior to transporting FPAs to the NCSX TC was identified
- Port welds will be individually leaked checked during FPA greatly reducing the likelihood of multiple vacuum leaks during initial pumpdown
- Extra PF conductor will be procured to have should the supplier have to wind an extra coil
- Task forces formed to expedite completing MC interface design; defining field period and final assembly sequences; and finalizing assembly tolerances
- Welding R&D program initiated to minimize the risk of unacceptable distortion during FPA
- Coil electrical tests will be performed at each station to ensure that the electrical insulation was not compromised during assembly operations
- Trained backups will be provided for all key personnel whose unavailability could impact schedule critical operations
- Rigidity of TC floor and assembly sled will be tested well in advance of when they are needed to allow time to make modifications (if needed).
- Additional budget for metrology equipment provided to minimize schedule impacts associated with equipment failure

Risk register summary

- Mitigation plans moved risks downward
- Presently have 7 moderate risks and 22 low risks
- Remaining moderate risks include
  - Damaging a MC during coil fabrication
  - Completion of MC interface design
  - The time to weld modular coils together
  - Cost uncertainties including escalation of stainless steel and Inconel prices, labor rates, overhead rates, and funding profiles
- No high risks were identified BUT risks with crisis-level consequences bear close examination even if the likelihood of occurrence is non-credible (P<1%)
  - Damaging a field period in transit to the NCSX test cell
  - MC/TF/PF coil failures following initial cooldown

Risk tracking

- New weekly construction management meetings focused on integration and schedule
- Monthly status meetings with all job managers will be expanded to include discussion of risk issues
- Expanded discussion of risk issues will be conducted monthly with the Director's Office
- Risk issues will continue to be discussed at the weekly meetings of the NCSX project management team chaired by the Project manager

Summary

- Important improvements in the risk management process have been made
- Near term priority placed on resolving high risk issues
- A risk register has been developed based on input from job managers and project management
- A fresh look at the risks prompted new mitigating actions which have been incorporated in project plans
- Cost and schedule contingencies updated based on updated risk assessment
- Expanded, regular review of significant risks planned within the project and with the Director's Office

Appendix

Risk register

NCSX Risk Register

No.	Job	Risk Description	Mitigation Plan	Likelihood of Occurrence [a]	Consequences	Risk Class	Basis of Estimate	Cost Impact ($k)		Schedule Impact (mos)	
								Low CI	High CI	Low SI	High SI
1	1354 7503	Additional trim coils may be required to suppress field errors from n>1 modes	Analysis being performed to firm up requirements	U	Marginal	Low	Costs could more than double the present estimate	+ $200	+ $400	+ 0.00	+ 0.00
2	1361	TF vendor produces a non-compliant coil requiring fabrication of an additional coil	Conductor for extra coil already procured. Ample float in schedule to avoid critical path impact.	VU	Negligible	Low	Increase PPPL Title III by ~1 man-month	+ $15	+ $35	+ 0.00	+ 0.00
3	1352	PF vendor produces a non-compliant coil requiring fabrication of an additional coil	Conductor for extra coil will be procured in advance and available to wind a new coil if required. Float in schedule appears adequate to avoid critical path impact.	VU	Negligible	Low	Increase PPPL Title III by ~1 man-month	+ $15	+ $35	+ 0.00	+ 0.00
4	1421	Modular coil interface design needs to change significantly from the baseline for unforeseen technical reasons	Task forces formed to expedite resolution of feasibility issues. Development activities are underway.	VU	Critical	Moderate	Design of the MC interface is on the critical path. Potential impacts include [1] additional design and development (4 engineers for 1-2 months) plus $100K M&S and [2] a change in the cost of field period and final assembly to a change in the design (+/- $300K).	($100)	+ $600	+ 1.00	+ 2.00
5	1421	As a result of the development trials for weld distortion, the welding time increases significantly above present allowance	Welding time estimates consistent with time requirements for first R&D article which appeared to have very low distortion. Risk goes away at conclusion of ongoing weld R&D.	U	Significant	Moderate	Nominal welding time may double. Estimate based on $300K/mo for FPA activities.	+ $0	+ $600	+ 0.00	+ 2.00
6	1451	Damage or loss of modular coil during VPI or testing requiring the conductor to be stripped off and re-wound	Continue to use same rigorous process used for first 12 coils during which there were no fabrication mihaps requiring re-winding a coil	U	Significant	Moderate	~$35K in materials; ~$380K in labor. 7.5 months to do work with the potential for a 2 month impact on the critical path.	+ $400	+ $450	+ 0.00	+ 2.00
7	1451	Failure of major piece of winding equipment (e.g., motor, gear box, etc.) resulting in extended downtime in a winding station	Use three remaining winding stations to continue MC fabrication while fourth station is being repaired	U	Negligible	Low	~$10K for equipment plus repair costs	+ $10	+ $30	+ 0.00	+ 0.00

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8	1810 7503	"Back office" support for FPA and final assembly becomes a chronic bottleneck, stretching out the time required to complete assembly operations	Additional support budgeted for Brown, Brooks, and Ellis providing "2 deep" back office support. Should be available to mitigate peak demands once training in key skills is completed.	VU	Significant	Low	Estimated impact is <2 months on the critical path. Cost impact covers up to 2 months of FPA/final assembly.	+ $0	+ $600	+ 0.00	+ 2.00
9	1810	Modular coil damaged during assembly requiring significant rework to coil	Equipment will be handled during FPA using carefully constructed procedures to minimize likelihood	VU	Negligible	Low	Nominally repaired with a 2-man crew within 2 weeks	+ $10	+ $20	+ 0.00	+ 0.50
10	1810	VV surface component (coolant tube, flux loop, or TC) damaged during FPA requiring significant rework	Equipment will be handled during FPA using carefully constructed procedures to minimize likelihood	VU	Negligible	Low	Nominally repaired with a 2-man crew within 2 weeks	+ $10	+ $20	+ 0.00	+ 0.50
11	1810	Unacceptable distortion in a field period when welding modular coil shims requiring	Likelihood of occurrence is very unlikely as a result of extensive welding R&D and careful monitoring during welding.	VU	Marginal	Low	Cut apart and re-weld two coils back together. Nominally a 2.5-man crew in 12 weeks.	+ $25	+ $35	+ 0.75	+ 1.25
12	1810	Field period damaged during loading, transport, or unloading from TFTR TC to NCSX TC	Extreme care will be taken when transporting a field period. Additonal reviews including external reviewers will be performed.	NC	Crisis	Low	*High impact-low probability event not covered by contingency*				
13	1815	Multiple vacuum leaks during initial pumpdown	Welds will be leak checked during FPA when leaks can be addressed without significantly impacting the critical path. Likelihood of many leaks appearing during initial pumpdown is considered extremely unlikely with this mitigation plan.	NC	Marginal	Low	Impact of having only a few leaks is covered in estimate uncertainty with present mitigation plan				

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14	7503	Insulation on TF/PF coil fails during initial cooldown and testing requiring in situ repair	Ist of each kind will be tested at cryogenic temperature at elevated (50% higher than routine field tests) voltage for faults to ground. All coils will be tested at RT at elevated (50% higher than routine field tests) voltage for faults to ground . Ring tests are performed to reveal low resistance turn-to-turn shorts at RT. These tests will be performed as part of the mfg acceptance testing. In addition, routine field tests will be performed on each assembly station to ensure that the electrical insulation was not compromised during assembly operations.	VU	Marginal	Low	Insulation fault in lead area is considered the most likely failure scenario. Repair in situ is assumed recovery scenario taking 2-3 months. 1 month to warmup and cooldown the stellarator core. 3 techs/1 engr for duration of active repair)1-2 months).	+ $50	+ $150	+ 1.00	+ 2.00
15	7503	Insulation on TF/PF coil fails during initial cooldown and testing requiring dismantling stellarator core	Ist of each kind will be tested at cryogenic temperature at elevated (50% higher than routine field tests) voltage for faults to ground. All coils will be tested at RT at elevated (50% higher than routine field tests) voltage for faults to ground . Ring tests are performed to reveal low resistance turn-to-turn shorts at RT. These tests will be performed as part of the mfg acceptance testing. In addition, routine field tests will be performed on each assembly station to ensure that the electrical insulation was not compromised during assembly operations.	NC	Crisis	Low	*High impact-low probability event not covered by contingency*				

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16	7503	Insulation on modular coil fails during initial cooldown and testing requiring in situ repair	C1 tested at full current at cryogenic temeprature. All modular coils will be tested at RT at elevated (50% higher) voltage for faults to ground. In addition, routine field tests will be performed on each assembly station to ensure that the electrical insulation was not compromised during assembly operations.	VU	Marginal	Low	Insulation fault in lead area is considered the most likely failure scenario. Repair in situ is assumed recovery scenario taking 2-3 months. 1 month to warmup and cooldown the stellarator core. 3 techs/1 engr for duration of active repair)1-2 months).	+ $50	+ $150	+ 1.00	+ 2.00
17	7503	Insulation on modular coil fails during initial cooldown and testing requiring stellarator core disassembly	C1 tested at full current at cryogenic temeprature. All modular coils will be tested at RT at elevated (50% higher) voltage for faults to ground. In addition, routine field tests will be performed on each assembly station to ensure that the electrical insulation was not compromised during assembly operations.	NC	Crisis	Low	*High impact-low probability event not covered by contingency*				
18	7503	Unanticipated problems with cryostat penetrations (icing, excessive condensation). May require warming up the stellarator core to effect repair with consequent impacts to critical path activities.	Rapid repair materials will be on hand.	U	Marginal	Low	Nominally repaired with a 4-man crew in 1 week with 3 weeks for warmup/cooldown (if required)	+ $15	+ $30	+ 0.25	+ 1.00
19		Loss or prolonged unavailability of certain key personnel from the project could substantially impact the schedule.	*See mitigation plans for individuals listed below.*								
	1901	Mike Cole (ORNL)	Brad Nelson is been budgeted (15%) on the project. Should Cole become unavailable, Nelson would step in and handle Cole's responsibilties until a suitable longer term solution was implemented.	VU	Marginal	Low	Estimated impact is <0.5 months on the critical path. No impact on FPA cost because impacted personnel would be assigned to other activities.	+ $0	+ $0	+ 0.00	+ 0.50

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	8203	Tom Brown (PPPL)	Bob Ellis has been budgeted along with a designer to provide support to Tom Brown in Design Integration during peak demands and pick up the slack for Brown if he became unavailable.	VU	Marginal	Low	Estimated impact is <0.5 months on the critical path. No impact on FPA cost because impacted personnel would be assigned to other activities.	+ $0	+ $0	+ 0.00	+ 0.50
	8204	Art Brooks (PPPL)	An EA/EM engineer has been budgeted to provide support to Brooks in Systems Analysis and Technical Assurance during peak demands and pick up the slack for Brooks should he became unavailable.	VU	Marginal	Low	Estimated impact is <0.5 months on the critical path. No impact on FPA cost because impacted personnel would be assigned to other activities.	+ $0	+ $0	+ 0.00	+ 0.50
	8205	Bob Ellis (PPPL)	An EA/EM engineer has been budgeted to provide support to Ellis in Dimensional Control Coordination during peak demands and pick up the slack for Ellis should he become unavailable.	VU	Marginal	Low	Estimated impact is <0.5 months on the critical path. No impact on FPA cost because impacted personnel would be assigned to other activities.	+ $0	+ $0	+ 0.00	+ 0.50
	1802 7401	Mike Viola (PPPL) Erik Perry (PPPL)	Viola and Perry will be cross-trained such that each could do the other's job	VU	Marginal	Low	Estimated impact is <0.5 months on the critical path. No impact on FPA cost because impacted personnel would be assigned to other activities.	+ $0	+ $0	+ 0.00	+ 0.50
20	1803 7503	Assembly sled for final assembly is not adequately stiff or does not provide repeatable motion	Functionality of sled will be determined first with concrete blocks and later with first FP. Ample time to make design modifications between arrival of the first and third FPs.	U	Negligible	Low	Nominal cost impact is 1 man-month of engineering design and up to half the fabrication cost of the sled	+ $25	+ $75	+ 0.00	+ 0.00
21	7503	TC floor is not adequately rigid for present metrology plan	Copper sheet and spongy surface removed from TC floor. Fiducials will be placed. Concrete blocks will be placed to see if floor is adequately stiff.	VU	Marginal	Low	Nominal cost impact is 2 man-months of engineering design and $50-150K for local reinforcement of building structures	+ $50	+ $200	+ 0.00	+ 0.00

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22	1421 7503	Modular coils are shorted across toroidal break between field periods causing problematic field errors	Need very low impedence, multiple shorts to get into trouble	NC							
23	8101	GPP projects not completed in time to support project needs	The crane and the HVAC systems are the main GPP projects that would need to be completed. The GPP projects have strong Lab and DOE oversight. Ample float is provided in the schedule so project delays due to GPP delays are not considered credible (P<1%).	NC							
24	8501	Coils are hooked up with incorrect polarity	Test during ISTP and fix	U	Negligible	Low	*Covered in estimate uncertainty with present mitigation plan*				
25	8101	Escalation of Stainless Sheet and Inconel higher than base escalation rates	Funding limits preclude early procurements to avoid escalation impacts	VL	Marginal	Moderate	See separate sheet - assume 3% to 20% higher per year escalation rate	+ $37	+ $266	+ 0.00	+ 0.00
26	8101	Escalation of Copper higher than base escalation rates	Funding limits preclude early procurements to avoid escalation impacts	VL	Negligible	Low	See separate sheet - assume 5% to 20% higher per year escalation rate	+ $11	+ $81	+ 0.00	+ 0.00
27	8101	Labor rates may be significantly lower/higher than projected		L	Marginal	Moderate	Escalation rate may be anywhere in the range of 2-5% instead of the nominal rate of 3.4% for labor. Schedule impact is due to annual funding constraints.	($500)	+ $500	(0.50)	+ 0.50
28	1810 1815 7503	Metrology equipment and general purpose tooling/ lifting equipment (e.g.cranes) not available to support the schedule	Maintenance contract mitigates impact of metrology equipment. Additional $200K budgeted for a 3rd laser tracker and/or spare metrology equipment. Should result in improved efficiency as well as failure mitigation.	U	Marginal	Low	Up to 2 week impact on FPA and critical path. FPA cost impact assumed to be $300k/mo.	+ $0	+ $150	+ 0.00	+ 0.50

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								Low CI	High CI	Low SI	High SI
29	1352	No suitable PF coil vendor submits bid. PF coils need to be built in-house.	PF is last major, special procurement. Sources sought received two qualified respondants. Capability to build at PPPL (and overseas) exists if needed.	U	Marginal	Low	Cost impact estimated to be up to $300k (1/3 of fabrication costs) for potentially higher labor rates at PPPL. No impact on critical path expected.	+ $0	+ $300	+ 0.00	+ 0.00
30	8101	Funding profile may not match assumptions which in turn could impact cost and schedule		U	Significant	Moderate	Cost impact derived from stretchout	+ $0	+ $0	(2.00)	+ 2.00
31	8101	Overhead rates may change signficiantly which in turn could impact cost and schedule		U	Significant	Moderate	Overhead rates are determined by institutional funding and are outside the project's control. +/- 2% on the rates are representative of variation in three-year institutional averages over the past 10 years.	($900)	+ $0	(1.00)	+ 0.00

[a] VL= Very Likely (P>80%), L=Likely (80%>P>40%), U=Unlikley (40%>P>10%), VU=Very Unlikely (P<10%), NC=Non-credible (P<1%)

Risk likelihood criteria

Probability of Occurrence		Criteria
Qualitative	Quantitative	
Non-credible	<0.01	Extremely unlikely occur anytime in the project life cycle, or the probability of the occurrence judged to be less than 1%.
Very Unlikely	>0.01 but <0.1	Very unlikely to occur anytime in the project life cycle, or the probability of the occurrence is judged to be less than 10%.
Unlikely	>0.1 but <0.4	Unlikely to occur in the project life cycle , or the probability of the occurrence is judged to be greater than 10% but less than 40%.
Likely	>0.4 but <0.8	Will likely occur sometime during the project life cycle of the project or its facilities, or the probability of the occurrence is judged to be greater than 40% but less than 80%.
Very Likely	>0.8	Very likely to occur sometime during the project life cycle or the probability of occurrence is judged to be 80% or greater.

Risk consequence criteria

Risk Consequences

Consequence of Occurrence			Criteria
Qualitative	Quantitative		
	Project Cost Threshold (% Total Project Cost)	Project Schedule Impact (months)	
Negligible	Cost Impact ≤ $100 k	Impact ≤ 0.5	• Small, acceptable reduction in technical performance • Minor threat to facility mission, environment, or people; possibly requires minor facility operations or maintenance changes without redesign, routine cleanup, or first aid • Cost estimates slightly exceed budget • Minor slip in schedule, with some potential adjustment in milestones required
Marginal	$100 k < Cost Impact ≤ $500 k	0.5 < Impact ≤ 1	• Some reduction in technical performance • Moderate threat to facility mission, environment, or people' possibly requires minor facility redesign or repair, moderate environmental remediation, or causes minor injury requiring medical intervention • Cost estimate moderately exceeds budget • Moderate slip in schedule and adjustment to milestones
Significant	$ 500 k < Cost Impact ≤ $ 1 M	1 < Impact ≤ 3	• Significant degradation in technical performance • Significant threat to facility mission, environment, or people; requires some facility redesign or repair, significant environmental remediation, or causes injury requiring medical treatment • Cost estimates significantly exceed budget • Significant slip in development schedule and modification of milestones or affect facility mission

Risk consequence criteria (continued)

Risk Consequences

Consequence of Occurrence			Criteria
Qualitative	Quantitative		
	Project Cost Threshold (% Total Project Cost)	Project Schedule Impact (months)	
Critical	$1 M < ETC Impact ≤ $5 M	3 < Impact ≤ 6	• Technical goals of project can not be completed • Serious threat to facility mission, environment, or people; possibly completing only portions of the mission or requiring major facility redesign or rebuilding, extensive environmental remediation, or intensive medical care for life-threatening injury • Cost estimate seriously exceed budget • Excessive schedule slip unacceptably affecting overall mission or project objectives
Crisis	ETC Impact > $5 M	Impact > 6	• Project can not be completed • Cost estimates unacceptably exceed budget • Catastrophic threat to facility mission, environment, or people; possibly causing loss of mission, long term environmental abandonment, or death