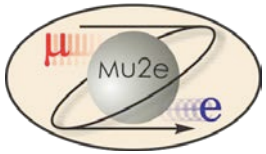
Fermilab

Solenoid Risk Analysis



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L2 for Solenoids

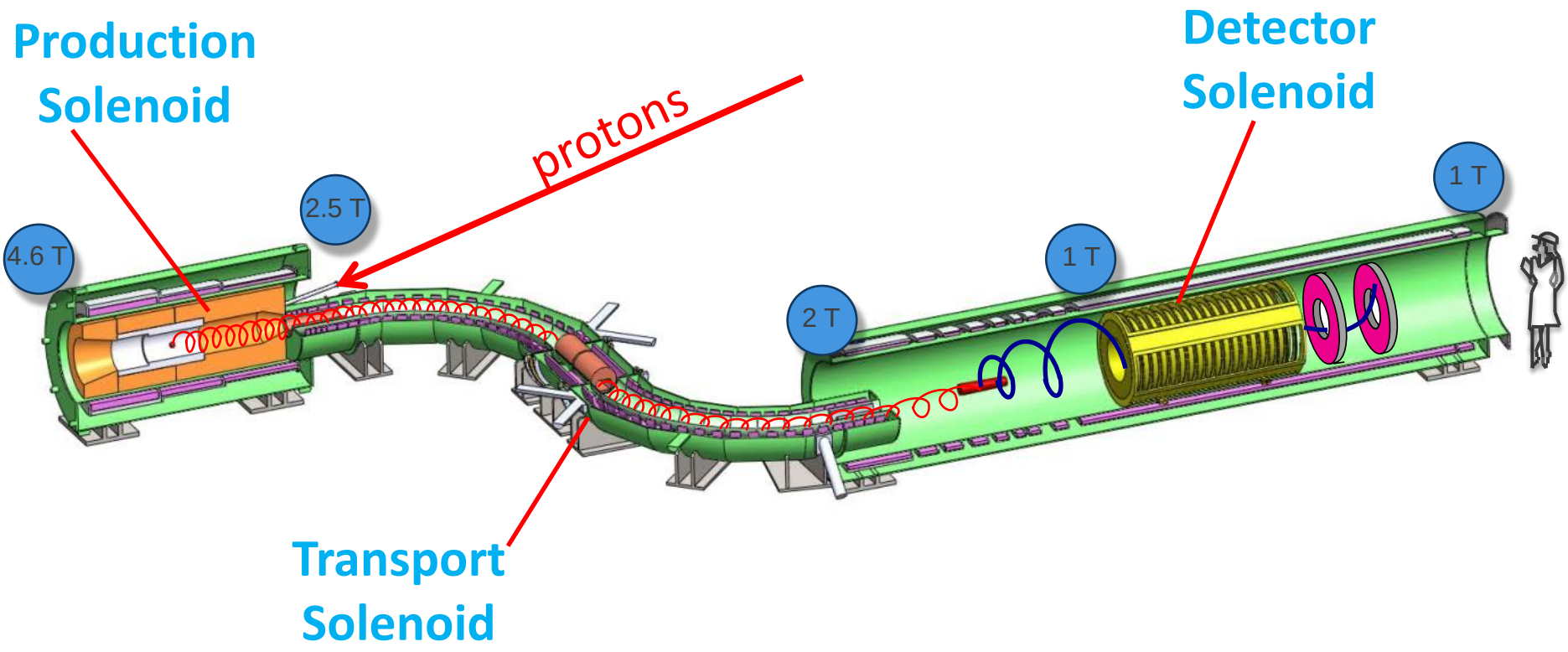
10/21-24/2014

Outline

- Solenoid Overview
- Risk identification Procedure
- How Risk is converted to $$$
- Risk list as input to Mu2e Risk Management Analysis
- Conclusions

Mu2e Solenoid System

- Three solenoids, provide magnetic field for experiment



Scope Review

- PS and DS: Final Design, Tooling and Fabrication by Vendor, from a detailed preliminary design and procurement spec. Final full-field testing at the vendor is an option.
- TS: Components including coil modules built by Vendor, from final drawings from Mu2e project. Final testing is to be performed at Fermilab
- Cryo distribution cold boxes and transfer lines built to print in industry
- For all solenoid deliverables, we are responsible for the installation and commissioning and co-responsible for interfaces

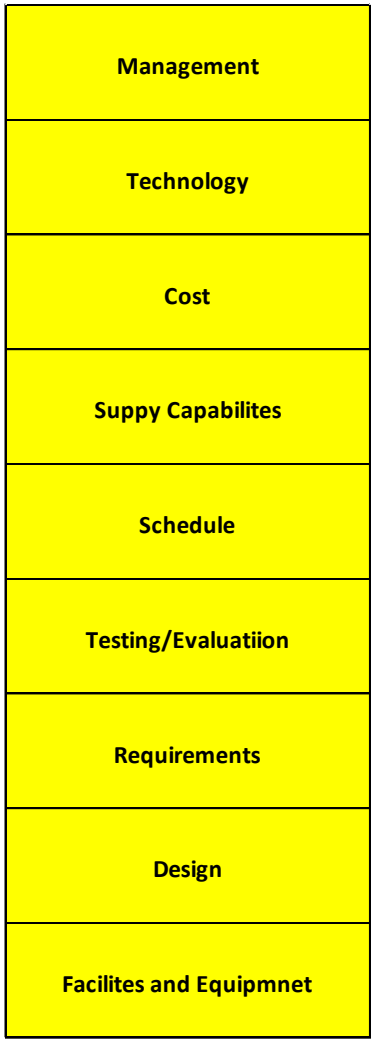
Contingency: Estimate Uncertainty vs. Risk

- Project holds contingency based on estimate uncertainty and risk
- Estimation uncertainty is based on maturity of estimation
  - Low uncertainty on vendor quotes, higher on engineering estimates.
- Many of the solenoid project estimates are at the preliminary stage➔ 30-40% estimate contingency
  - This is reflected in the RLS and shown in Mu2e project Cost Book
- Exception is the PS and DS fabrication.
  - Set at 15%
  - We have a vendor quote on the PS and DS but still holding contingency, since the contract is not signed yet.
  - Holding contingency based on expected change orders
    - 10% is reasonable based on “lessons learned”
- Additional solenoid contingency based on risk
  - This is the basis of our analysis here

Mu2e Risk Strategy

- Solenoid Risk analysis is part of the a larger overall Project risk analysis
- See Ron Ray's talk (P2-Project Overview)
  - Explains the overall Mu2e Risk Strategy
- Also presentation by the Mu2e Risk Manager Mike Dinnon (B01-2 Risk Analysis)
  - Explains how Primavera Risk Analysis Tool is implemented

Developing Solenoid Risk Register



- Risk can be classified under 9 common risk areas
- These risk areas are explained in detail in Table 1 of the Solenoid Risk Analysis Document
- This was used not only to identify if the item is a true risk but also a guide to bottoms up risk identification

Generating Risk Register Bottoms Up

- We formed a small working group to generate the Mu2e Solenoid Risk Register
- Regular meeting participants: Michael Lamm (Solenoid L2), Tom Page (Project Engineer), Vadim Kashikhin (Production Solenoid L3), Mau Lopes (Transport Solenoid L3), Marc Buehler (Detector Solenoid L3), Jeff Brandt (Installation, Integration and Commissioning L3), Ruben Carcagno (External member, LARP Project Engineer)

Generating Risk Register Bottoms Up

- First step in this process is to make list of possible problems that could occur during all phases of the Solenoid resource loaded schedule.
- 5 main areas from deliverables
  - PS, DS, TS, Cryo distribution, Installation and Commissioning
- Also consider problems associated with interfaces
  - Both internal and external

Generating Risk Register Bottoms Up

- Step II. Like-problems were combined into common risk register entries
  - i.e. problems that result in the same consequence
- For example, all PS coil fabrication errors combined into one risk
  - hi pot failure, turn to turn short, voids or cracking in epoxy largely speaking have the same result: need to remake the coil.
  - Then assigning a probability to the occurrence of this aggregate set of problems.
    - We felt that this resulted in a more realistic estimation
- Many risks in common risks amongst the PS/DS/TS, but we consider them separately because they will likely have different probabilities and impacts.

Generating Risk Register Bottoms Up

- For each Risk, an estimate was made of M&S, Schedule impact and probability
- Estimate probability from own experience + discussions from “lesson learned” and AOC
- Estimate M&S and Schedule Impacts based on Resource Loaded Schedule and our own experience
  - This in turn is based on vendor supplied costs and schedules particularly for the PS and DS.
- Risks that had a low probability AND low cost/schedule were eliminated from consideration
  - Guidance from the Mu2e Risk Management Plan

Noteworthy Risk items

We list some of the more noteworthy Solenoid risk register entries

PS/DS

- Coil Failure during fabrication*
- Final magnet does not pass final acceptance test

TS specific

- TS cooling system does not perform as expected

Cryo Distribution

- Cryogenic Feedbox has a cold leak

Installation, Integration and commissioning

- PS shows up late, have to rent crane to install through PS Hatch

*Note: On recommendation of our AOC, we are ordering enough spare PS conductor to make a replacement PS 3-layer coil. Prior to this we only had enough spare conductor to replace one layer of this PS coil. This mitigates a larger cost and schedule risk.

Sample Risks (PS)

Complete table located in the “Mu2e Solenoid Risk Analysis Document.

Table entries:

- Risk identifier, title and description
- Task most affected by risk
- Estimate of schedule delay
- Estimate of M&S
- Estimated occurrence probability

Risk ID	Risk title	Risk Description	Task Most Affected	Estimated schedule Delay (in days)	Estimated M&S k$	Estimated Probability of Occurance
Production Solenoid						
SOL-171	PS Production cable does not meet specification	Schedule delay because first production article of the PS conductor does not meet specifications. This would require another iteration that could take up to a year.	47504.2.051734	250	0	10%
SOL-172	PS Magnet fabrication failure due to vendor supplied process or component	Schedule delay because of coil failure during fabrication. The most likely high impact event would be a hipot failure once the coil has been potted. Coil and superconductor would likely have to be scrapped.	47504.2.051734	250	1250	10%
SOL-173	PS Completed magnet does not pass acceptance tests at vendor	Vendor is required to perform a series of acceptance tests, including a cool down to Liquid Helium temperatures, but not a full current excitation test. These tests are in addition to the QC tests performed during fabrication	47504.2.051734	125	0	10%
SOL-174	PS Vendor delays not caused by FNAL	At contract signing, vendor agrees on schedule. However, delays may occur due to vendor-internal problems	47504.2.051734	65	0	25%
SOL-175	PS Magnet is damaged during shipping and handling	Vendor is responsible for the shipping and handling of magnet. There is a possibility that the shippers mishandle the magnet. This could also cover "acts of nature" that are beyond the control of the vendor but still their responsibility.	47504.2.051734	250	0	5%
SOL-176	PS Operational failure during final acceptance tests at FNAL.	There is a final acceptance test which include excitation to full field. Since most other acceptance tests are performed prior to shipping, the most likely cause of failure here would be conductor failure	47504.2.051734	500	500	10%

Translating Risk into $'s

- Multiple M&S-related risks are fairly easy to handle, given the amount and probability
- Multiple schedule delays are more complicated
  - Risk ➔ directly affect duration of one or more tasks.
  - Because each task has a predecessor/successor, schedule related risks are very correlated.
  - Tasks that are on the critical path will extend the project duration
    - Standing army effects for all "level of effort tasks"
  - Tasks that off critical path may or may not add any significant costs
    - If delay is long it enough, it will go on the critical path for part but not all of the delay duration.
    - Even off critical path, task can be on critical path for deliverable
- For this reason the project is using the Primavera Risk Analysis Tool.

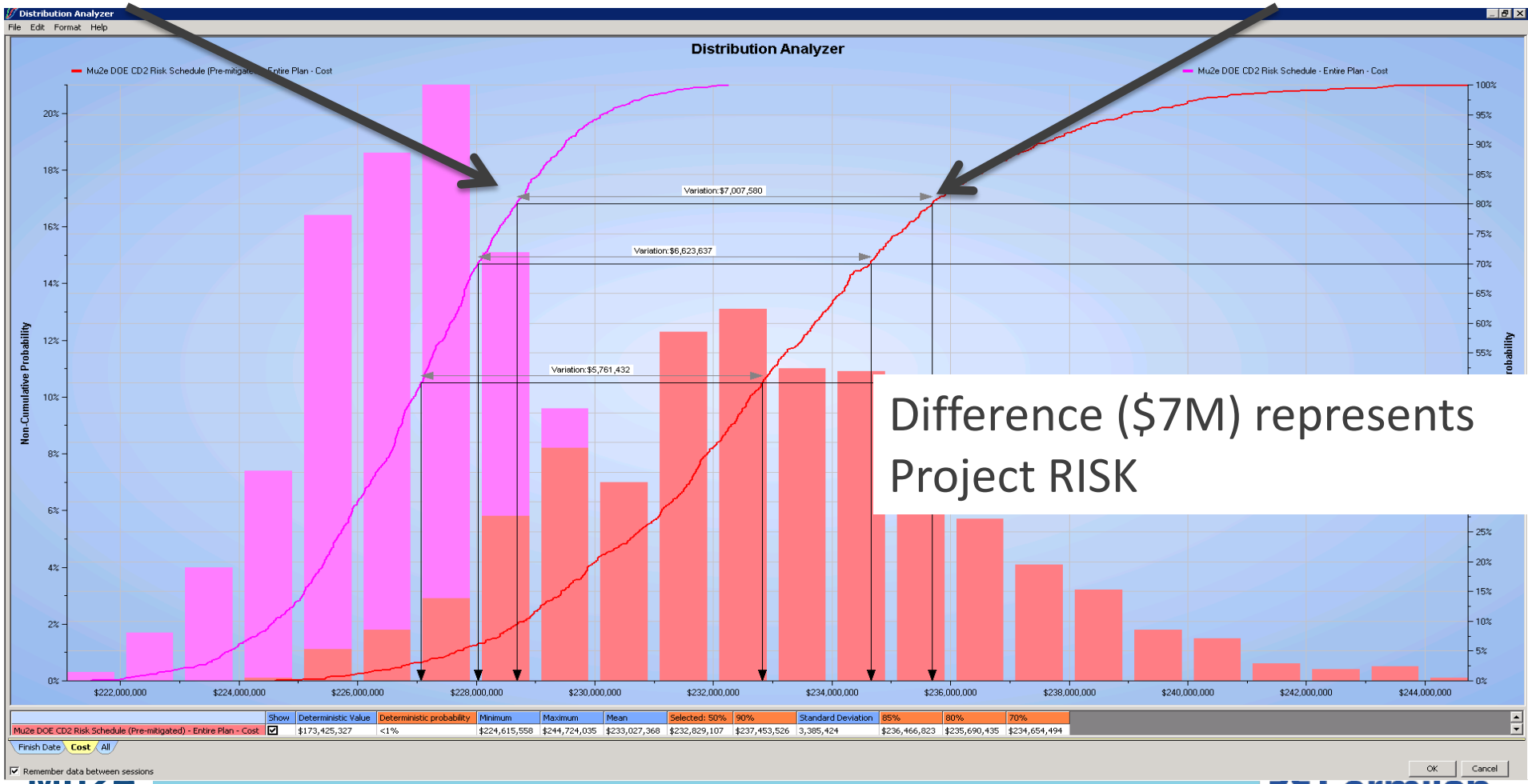
Mu2e Risk Strategy and Primavera Risk Analysis Tool

- Primavera is the Project Scheduling Software Used by all Fermilab Projects
- Primavera Risk Analysis tool works with directly with Primavera
  - Properly accounts for schedule correlations
  - Identifies key risks and orders them in significance
  - Graphical interfaces

Primavera Risk Analysis Result

80% of “non risk” MC scenarios fall below this value

80% of “risk” MC scenarios fall below this value



Difference ($7M) represents Project RISK

Risk Contingency Associated with Solenoids?

- Difficult to determine exactly because cost/schedule correlations with rest of Mu2e threats.
- Project performed separate Monte Carlo analyses to check the primavera tool
- Assumptions
  - Cost of delaying project by one year : ~$2M
    - Validated by running Primavera, delaying project by 1 year, running accounting software for “standing army” and escalation costs
  - Assume risk entries have little or low correlations
    - Valid since most events that occur at the same time have a low probability of occurrence

How much Risk Associated with Solenoids?

Using this methodology

- Project risk is estimated to be $6.5 M with a 80% cumulative probability.
- This is in very good agreement with $7M Primavera estimate
- $3.5 M can be associated with solenoid-related risks
- Thus a little over ½ the Risk contingency is associated with the Solenoids

Conclusion

- A bottoms up risk analysis has been performed on the mu2e solenoids, as part of a larger risk analysis for the mu2e project
- 32 risks were identified with an associated probability, cost and schedule impact (there is also one opportunity identified)
- Using the Primavera Risk Management tool, these risk when combined with other Mu2e risks predicts a ~$7M risk contingency with an 80% cumulative probability. This agrees well with a $6.5M risk “Excel based” Monte Carlo analysis.
- $3.5 M can be associated with solenoid-related risks
- Performing this analysis has helped us to identify the highest risk solenoid elements, and insure that the project is prepared in the unlikely event that these risks come to fruition.