SYSTEMS ENGINEERING AND INTEGRATION ON THE FRIB PROJECT*

D. Stout#, T. Borden, N. Bultman, R. Frazee, M. Leitner, P. Nguyen, T. Russo, E. Tanke, C. Thronson, Facility for Rare Isotope Beams, Michigan State University, East Lansing MI, 48824 USA

Abstract

The Facility for Rare Isotope Beams (FRIB) will be a world-leading, DOE Office of Science national user facility for the study of nuclear structure, reactions, and astrophysics on the campus of Michigan State University (MSU).

Systems Engineering and Integration has been implemented at the outset to ensure that a requirements-driven design process is followed, and to ensure intra and inter-system compatibility. Top-level requirements have been allocated and subsequently elaborated between the Accelerator Systems, Experimental Systems, and Conventional Facilities. FRIB has developed a number of methods and tools to track requirements, establish interfaces, monitor design progress, and ensure overall system integration. These will be described in the paper.

FRIB PROJECT INTEGRATION

A superconducting, heavy-ion, driver linac will be used to provide stable beams of >200 MeV/u at beam powers up to 400 kW (~650 electrical micro-amps for uranium). The stable beams will be used to produce rare isotopes by in flight fragment separation. After fragment selection, the rare isotopes will be used at velocity (~0.5c), stopped, or reaccelerated. The MSU-led design and construction effort is supported by collaborations with many National Laboratories and other scientific institutions [1].

FRIB is integrated both vertically and horizontally. The vertical integration is achieved by the Systems Engineering methods discussed in the next section. Horizontal integration is achieved by the project organizational structure and by adherence to a consistent design process.

Project Engineers are identified within the three main FRIB Divisions, Accelerator, Conventional Facilities, and Experimental, and are responsible for integration within their Division.

The overall project design process is shown in Figure 1. At each significant project design phase, the key design products and expectations are defined with respect to the major design aspects: requirements, interfaces, drawings and specifications, manufacturing, and project management. At the beginning of each major design phase (i.e. preliminary or final design) deliverables for each sub-system are identified. These include specific analyses, tests, and prototypes that must be completed to demonstrate readiness for the next design phase, or for construction.

Defining the deliverables for each sub-system ensures coherence between the sub-systems, either by keeping their efforts on a similar schedule, or by clearly defining the interface points between sub-systems on different development schedules. This latter point is important since most projects usually cannot complete all design work simultaneously due to cost and design resource limitations. The other main advantage of clearly defining the deliverables and design expectations is that each sub-system manager then has a clear work plan for design. On FRIB these deliverables are used as part of the Earned Value Management System to measure and quantify design progress.

SYSTEMS ENGINEERING AND INTEGRATION OVERVIEW

Systems Engineering, as defined by the International Council on Systems Engineering [2], is an inter-disciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem: Performance; Operations; Cost & Schedule; Training & Support; Test; Manufacturing and Disposal. Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Implementation of Systems Engineering can be tailored for a specific industry or laboratory. Many industries can amortize software, staffing, training, and set-up expenses over multiple platforms or projects. For one-off projects like FRIB, the same methods can be used, but off the shelf software and a leaner System Engineering staff are more appropriate.

Irrespective of the scale of the implementation, the "V" model is at the core of the Systems Engineering approach, and has been fully implemented for FRIB. This model breaks a system into sub-systems, equipment, and components, with specific requirements and interfaces at each level of decomposition. The right hand side of the "V" model is the subsequent aggregation of components, equipment, and sub-systems into a fully functioning system. This aggregation is accomplished by increasingly sophisticated levels of testing and integration. A requirements-based design is fundamental to the use of this model. By starting from a limited number of top-level system requirements, one can define the overall architecture and decompose the project into essential sub-

*This is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, by Michigan State University and by the State of Michigan.

#stout@frib.msu.edu

System Design Process				
Project Phase:		Conceptual Design	Preliminary Design	Final Design
Design Aspect:	Requirements	Conceptual Design Report Parameter List	Parameter List System Req. Documents (SRDs)	Final Parameters and SRDs
	Interfaces	Interfaces defined	Interface Control Documents Interface Drawings	Final Interface Drawings
	Drawings	Process Flow Diagrams Block Diagrams CAD Model (for space reservation)	Piping and Instr. Diag (P&ID) Single Lines (electrical) General Arrangement/Assembly	Final Drawing Package
	Engineering & Specifications	Trade-off Studies and Analyses	Sub-system Specifications Engineering Analyses - Mech., Struct., Thermal - Dynamic, Electric., Circuit - Modeling, simulations	Final Component Specifications
	Manufacturing & Inspection	Manufacturing concept	Manufacturing Plan	Manufacturing Plan - Specs, procedures - Inspection/QA plan Assembly Installation Plan Factory Testing On-site Testing & Commissioning
	Project Management	Schedule Risk Assessment Cost Estimate Work Plan for Next Phase	Schedule (revised) Risk Assessment (revised) Cost Estimate (revised) Work Plan for Next Phase - Drawing Index - Specification Index	Schedule (revised) Risk Assessment (revised) Cost Estimate (revised) Work Plan for Next Phase

Figure 1: FRIB System Design Process Summary showing deliverables by phase and design aspect.

systems. Most sub-systems for FRIB are based on well-known accelerator technology.

REQUIREMENTS AND INTERFACE DEFINITION

Overall FRIB requirements were finalized during the conceptual design phase of the project. These requirements were captured in a draft Project Execution Plan, Project Requirements Document, and a Parameter list. The first two documents capture all requirements, and the Parameters list identifies the relevant sub-systems and some of their features. During preliminary design, these requirements were further divided into several "System Requirements Documents" for the accelerator, conventional facilities, experimental systems, personnel protection system, cryogenic plant and others. Because these are high level requirements, they were assigned to the specific sub-systems responsible for achieving them. The project captured these in a "Requirements Tracker", a spreadsheet capable of ensuring all requirements were assigned to a responsible system/sub-system. The tool also allows for selecting the requirements specific to a certain sub-system for verification at design reviews or during testing. Another important feature is that the tracker captures emerging safety requirements, assigns these requirements to a specific work element, and verifies their accomplishment. For example, radiation shielding and oxygen-deficiency hazard requirements are developed through calculations and analyses as the design progresses. The tracker facilitates capturing such evolving requirements.

Another essential area that requires definition and monitoring are interfaces, such as physical locations / connections, utility requirements, beam-handoff parameters, instrumentation and data interchanges, etc. FRIB developed an "Interface Tracker", an excerpt of which is shown in Figure 2, to identify interfaces and to retrieve the relevant information for a specific interface. Initial interface assignments, between magnets and power supplies for example, were identified. The appropriate interface documents were prepared, approved, and submitted to the FRIB document control center. The interface tracker visually identifies the interface and provides a hyperlink to the associated documents. It also quantifies the progress made in defining interfaces, so the project can ensure that interfaces are frozen before detailed design is started.

DESIGN VALIDATION

Initial design validation is the responsibility of the cognizant team. FRIB also conducts project-level reviews of all major sub-systems at the 30%, 60%, and 90%

ISBN 978-3-95450-138-0

Avg.% 67 / %avail.			T.3.02 Cryogenic Systems	T.4.02.01 Target Area Utilities	T.4.02.02 Target Area Remote Handling	T.4.02.03 Target Area Non-Conv. Utilities	T.4.03.01 Frag. Sep. Beam Physics	T.4.03.02 Diagnostics	T.4.03.03 Preseparator Magnets	T.4.03.04 Preseparator Mechanical Systems	T.4.03.05 A1900 Reconfiguration	T.4.03.06 Power Supplies	T.4.03.07 Vacuum Systems
71	Cryogenic Systems	T.3.02	O										
75	Target Area Utilities	T.4.02.01	O	O									
50	Target Area Remote Handling	T.4.02.02	O	O	O								
25	Target Area Non-Conv. Utilities	T.4.02.03	Y	Y	Y	O							
100	Frag. Sep. Beam Physics	T.4.03.01	O	O	O	O	O						
50	Diagnostics	T.4.03.02	O	O	Y	O	V	O					
78	Preseparator Magnets	T.4.03.03	V	O	V	Y	V	O	O				
43	Preseparator Mechanical Syst.	T.4.03.04	Y	O	Y	Y	O	Y	Y	O			
75	A1900 Reconfiguration	T.4.03.05	V	O	O	O	O	V	O	O	O		
100	Power Supplies	T.4.03.06	V	V	O	O	O	O	V	V	V	O	
100	Vacuum Systems	T.4.03.07	O	V	V	O	O	O	V	V	V	O	O

Figure 2: Excerpt from "FRIB Interface Tracker".

completion points. The 30% review corresponds to the completion of the Preliminary Design Phase in Figure 1, and the 60% and 90% reviews are conducted during the Final Design Phase.

Currently the project is conducting 60% and 90% reviews. The purpose of the 60% review is to ensure all requirements and interfaces are finalized, all engineering analyses have been completed and support final detailed design, and the design addresses quality, manufacturing, and environmental, safety and health requirements. The 90% review is conducted to confirm the design is complete and ready for procurement.

External expert reviewers are essential for effective reviews, and FRIB policy requires independent review of high level of care systems, such as personnel protection systems.

DESIGN MANAGEMENT

FRIB uses key performance indicators to summarize the engineering progress over time. Progress is based on completion of interfaces, completion of 60% and 90% reviews, and final drawing/specification completion. A excerpt of a Design Progress Dashboard is shown in Figure 3.

Experimental Systems Division

31-Aug-13		Interfaces (%) From Tracker	60% Design Review (%)	Drawing (BTP) or Specification (BTS) % Complete	90% Design Review (%)	Overall Design Progress (%)
Division Average:		68	41	17	10	45
Target Area Utilities	T.4.02.01	75	100	90	90	83
Target Area Remote Handling	T.4.02.02	50	0	10	10	41
Target Area Non-Conv. Utilities	T.4.02.03	25	100	10	10	52
Diagnostics	T.4.03.02	50	0	0	0	38
Magnets	T.4.03.03	78	50	30	0	54
Preseparator Mechanical Syst.	T.4.03.04	43	0	0	0	36
A1900 Reconfiguration	T.4.03.05	75	0	0	0	41
Power Supplies	T.4.03.06	100	100	50	0	68
Vacuum Systems	T.4.03.07	100	100	0	0	60
Low Level Controls	T.4.03.08	60	0	0	0	39
Machine Protection System	T.4.06.01	100	0	0	0	45
Personnel Protection Systems	T.4.06.02	88	100	10	0	61

Figure 3: "FRIB Design Dashboard" showing progress.

Progress is plotted monthly to make sure FRIB is on track for major milestones. A sample graph is shown in Figure 4.

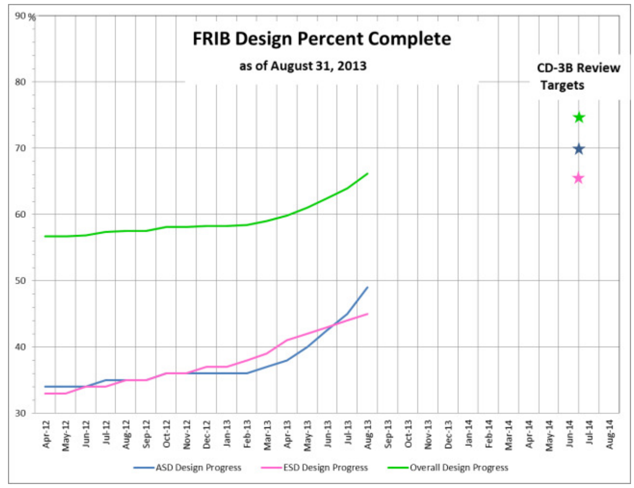

Figure 4: Sample Monthly Design Progress Report indicating progress and targets.

COMPONENT AND SUB-SYSTEM VALIDATION

The Project uses formal Acceptance Criteria checklists to identify the criteria that must be satisfied and to document the actual verification that the criteria is met. These lists are used for fabrication, testing, and will be used for installation and integrated testing. The Requirements Tracker previously mentioned supports criteria development, and it also captures the actual verification.

SUMMARY

FRIB has implemented an effective Systems Engineering and Integration Process:

- Tools are in place and used to manage requirements and interfaces; metrics provide managers current status of the design effort
- Review and validation processes will ensure designs meet requirements, including fabrication, installation and testing requirements.

REFERENCES

[1] J. Wie *et al*, "Progress towards the Facility for Rare Isotope Beams," These Proceedings.
[2] International Council on Systems Engineering, http://incose.org/

ISBN 978-3-95450-138-0