



# Cryomodule Technical System Review

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Date

Event

**Global Design Effort**

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# Outline: Cryomodule Cost Estimate

- KEK cryomodule cost estimate
- U.S. region cost estimate
- European region cost estimate---even though we don't have anything specific



## Status: Engineering & Cost Estimate

- KEK cryomodule cost estimation model (1)

- **The cost estimation by KEK covers**

- Cold mass components (material and machine processing cost) in the one cryomodule
  - Vacuum vessel and vacuum bellows
  - Gas Return Pipe (GRP) and support system of cavity helium vessel
  - Pipes and bellows for supplying liquid helium, and cooling pipes for thermal shields.
  - Thermal radiation shields
  - Support posts and connection parts between posts and vacuum vessel
- Assembly cost of the cold mass and cavities into one cryomodule
- Mass production effect on the cryomodule cost by the learning curve
- Cryomodule tests during the period of mass production (5 years)



## Status: Engineering & Cost Estimate

- KEK cryomodule cost estimation model (2)

- **Conditions of the cryomodule cost estimation**

- For the mass production, we assume the 700 cryomodules, not 2100 cryomodules. Following the production profile by the US group (700 model), the maximum construction rate is 200 cryomodules per a year.
- We are dealing with the non-quadrupole cryomodule for the cost estimation.
- The studied cryomodule is basically the Type III. No complete design of Type IV cryomodule for ILC.
  - We consider that the cryomodule components of Type IV are close to those of the Type III cryomodule for the cost estimation.
- In the cost estimation of the cryomodule test, the water and electrical power are not included.



# Description of Cost Methodology

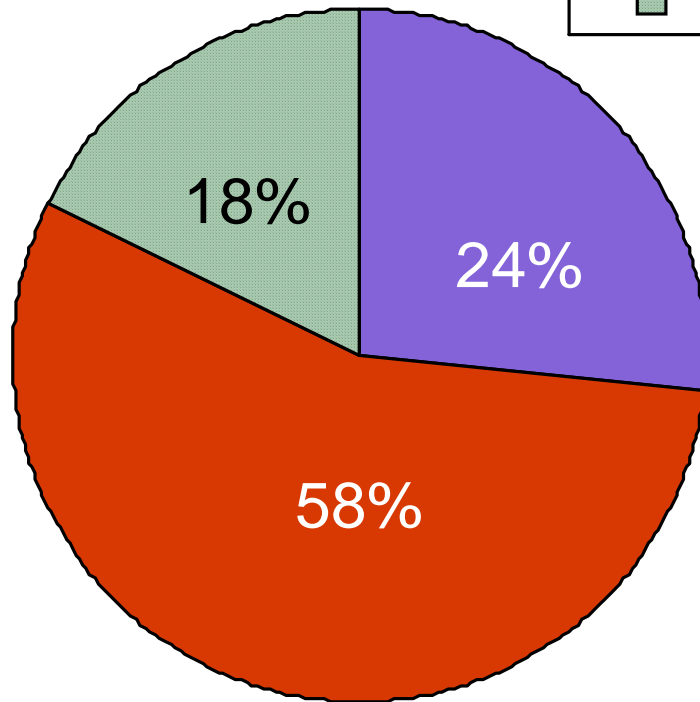
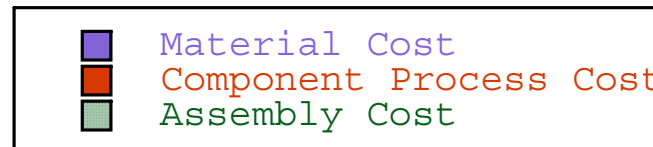
- Strategy of the cryomodule cost estimation by KEK
  - **Making the cost table of the cold mass components of one unit cryomodule with two Japanese companies**
    - Hitachi
      - Making the cost table (material and manhours of the component processes) of the cold mass components of the STF-Phase-1 cryomodule.
      - Design of the STF-Phase-1 cryomodule is based on the TTF Type III cryomodule. The cryomodule cross section is very close to the TTF Type III cryomodule.
      - Estimating the cost of the ILC cryomodule based on the STF-phase-1 cryomodule cost.
    - Toshiba
      - Making the cost table of the TTF Type III cryomodule (under construction).
  - **Assembly cost**
    - Studying the assembly processes and man powers from DESY #6 cryomodule assembly.
    - Making the table of the processes and man powers for the STF cryomodule by Hitachi and the TTF type III cryomodule by Toshiba.



# Description of Cost Methodology

- The profile of the material, component process and assembly costs for the ILC cryomodule by Hitachi

ILC Cryomodule Cost  
Estimated by Hitachi



More than 75 % of the cryostating cost is the labour cost of machine-processing components and assembling the cold mass.



# Description of Cost Methodology

## – Learning curves

- The unit cost decrease with a constant ratio every time when the total accumulated number of the manufactured items becomes double.

$$Y = Y_1 \times P^{(\text{Log}X / \text{Log}2)}$$

Y: Production manhour at the x-th cryomodule

$Y_1$ : Production manhour at the 1-st cryomodule

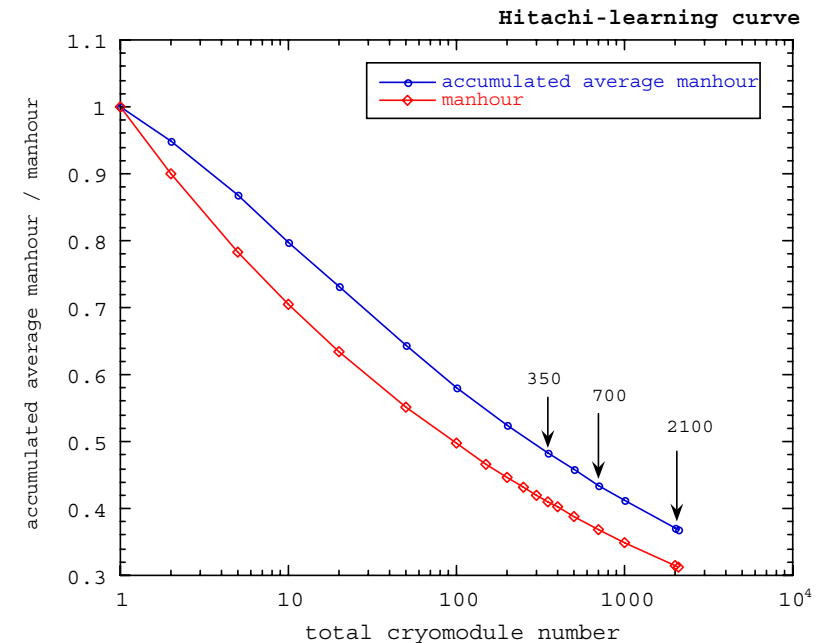
X: Accumulated total number of the cryomodule

P: Learning ratio

- This learning curves are applied on the material and process costs for the components and the cryomodule assembly.

## – Risk factors

- The risk factors are not introduced for the cryomodule cost estimation. The value of the risk factor strongly depend on the perfection of the cavities. When making the parameter clear, we apply the value on the assembly cost of the cryomodule.

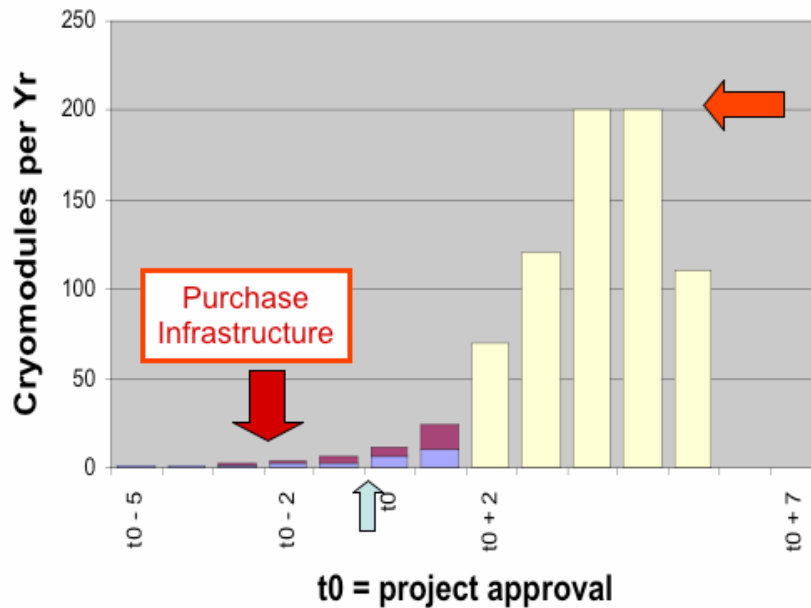




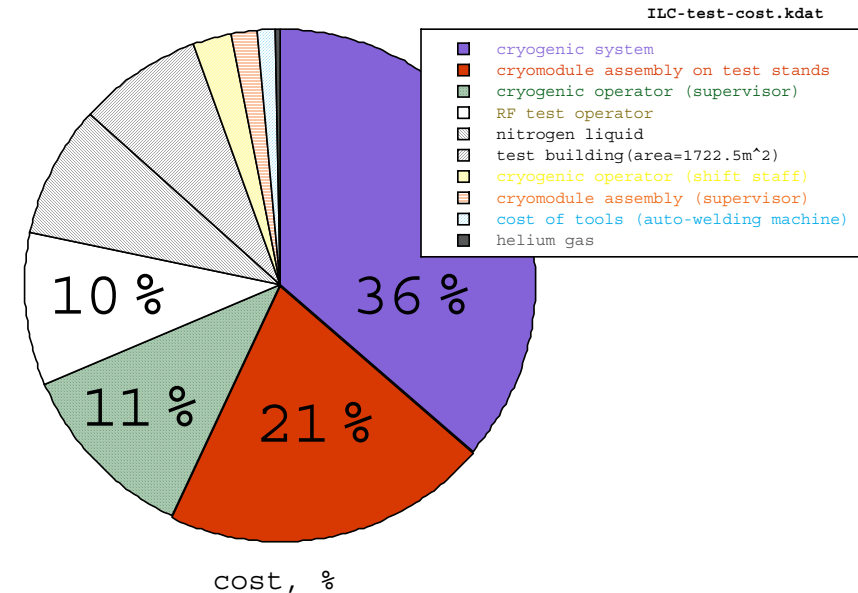
# Description of Cost Methodology

## – Cryomodule test

- The tests of 200 cryomodules per a year following the production profile proposed by US Gp.
  - In the cost estimation by KEK, it is assumed that 20 cryomodules should be tested during the 5 weeks, and the tests are continued for 50 weeks per a year.
  - Required refrigerator: 1.6 kW at 4.4 K and 3 kW at 80 K.



Cost profile of the cryomodule test







# Next Steps (KEK)

- Next steps for the cost estimation
  - **this workshop**
    - We have to confirm the studying items and the strategy of the cost estimation between three regions.
  - **between this and the Valencia workshop**
    - Making the optimized mass production model of the 700 and 2100 cryomodules with estimating the actual works and positioning the components in the factories.
    - The learning ratio should be studied more and be applied separately on each subject.
    - Making the list items of the components and the process including facilities almost same level for the cost estimation between three regions.
      - It is OK that the cost values are secret, however the study items and components should be clear between three regions.
    - The cost estimation of the cryomodule component is based on the STF cryomodule design. The cost model of the cryomodule and assembly process should be improved by being referred to the component design of the TESLA cryomodule.
      - For example, thermal radiation shielding plates, finger welding process.
      - Introducing auto-welding machine for assembly as much as possible.



## Status of the US Cost Model Effort

- Cost estimate developed by a team led by Rich Stanek (FNAL) and Warren Funk (JLab)
- Estimate is inclusive of all aspects of cryomodule construction, using a combination of inputs from JLab (dressed cavities) and FNAL (string & cryomodule assembly)
- It is a work in progress that will get refined using feedback from the DCB/GDE at this meeting
- Prior to the Valencia meeting we plan to incorporate a true dynamic Simulation Model
- Have not attempted to fit this estimate into any “standard” DCB-generated WBS format yet (Excel based estimate at this time)
- Still need to generate the risk/probability distribution
- The current estimate assumes a 40% contingency added to the total cost



# Work Breakdown Structure

- WBS has three Level 2 elements:
  - **Project Management**
    - Overall PM Office => An estimate of the effort and cost associated with “running the cryomodule project” including incorporating sound project management techniques and preparing for reviews
  - **Infrastructure**
    - Facilities required to produce/process/assemble/test/store components and finished assemblies (twelve facilities in total)
  - **Cryomodules**
    - M&S and SWF (touch labor) costs are captured on a per unit basis and multiplied by the number of cryomodules required



# Cost Model Assumptions

- Duration => Seven year project
  - Takes 2-3 years to build up infrastructure
  - Operate infrastructure (keep it functional) for the next 4-5 years
  - **Time assumptions will get revisited and optimized when the Simulation Software is implemented**
- One vendor
- Ramp Rates are not included yet
  - **Working with average rates**
- Learning Curves
  - **Used in cavity part of model, not yet in cryomodule assembly**
- Starting Point
  - **At the start of the Project we know what we want to build (all R&D is complete) and how we want to build it**
- Extra cryomodules
  - **Included in the model to allow for a failure rate during final test**



# Inputs to Model

- Total Number & Type of cryomodules
- Total years available to fabricate cavities & cryomodules
  - **assume it takes 2-3 yrs to put infrastructure in place**
  - **assume there is an offset between time for cavity fabrication and time to assemble cryomodules (currently 1 year but adjustable)**
- Unit Prices & Labor Estimates for components
  - This is where learning curves & quantity discounts would be applied
- # of shifts required per stage of cavity and cryomodule fabrication, processing, assembly and test
- Several different yield factors
  - % of cavities that fail vertical qualification test
  - % of failed cavities that require additional electro-polish
  - % of cavity strings that need to be reworked
  - % of cryomodules that fail final qualification test



## Cost Model Integration (JLab & FNAL)

- Worksheets from Warren Funk (JLab – Dressed Cavities) were added to the FNAL base workbook to complete the Total Cryomodule Estimate
  - Sheets/cells are referenced to one another as part of integration
- Parameter Page was developed to capture key inputs and assure that both parts of the model used the same numbers
- Tried to keep as much commonality as possible
- Differences in philosophy still exist but are being discussed to gain consensus (weekly meetings)
- Cavity string assembly was estimated by both Labs and proved to be beneficial in identifying all costs



# Project Management

- M&S estimated as 1% of sum of Total Infrastructure + Total Cryomodule costs
- SWF estimated based on 10 person Project Management Team for full 7 year duration
- This is an area that will see more refinement as the model continues to be developed



# Infrastructure

- Tried to identify and cost every facility required
- Quite probable that
  - Some facilities would be established by the vendors
  - Several of these facilities would be combined into one
- Facilities are referenced to a particular configuration (one facility unit produces x units in this amount of time) and then scaled for actual model inputs (that's why some quantities are not integers)
- Each facility has three L4 elements
  - Building (used base cost of \$250/sf)
  - Equipment (# and type of task specific equipment)
  - EDIA construction, maintenance & oversight
- Labor estimates are to construct maintain and oversee operation of the facility, not touch labor on the cryomodules, except in case of storage/prep buildings (function is clearly defined)
- **Cost of infrastructure is affected by inputs/assumptions to the model**
  - # of cryomodules, years available for fabrication, shift operation...





# Cryomodules

- Different types and quantities of cryomodules have been included
  - **Four types (cells for final 3 types all referenced off first unit)**
    - Standard with quad
    - Standard without quad
    - Special (6 cavities / 6 quads)
    - Special (8 cavities / 2 quads)
- All M&S and SWF costs on a per unit basis have been captured and then multiplied by the number of units
- Some costs are “common” and independent of exact number of units
- All the “touch labor” associated with a cryomodule as well as EDIA on a per unit basis has been captured
  - **Coupled with using FTE Yr units => create very small numbers**
- **We used agreed upon # of shifts (from May DESY meeting) for assembly steps inside/outside clean room**



# Next Steps

- Continue to validate and refine the model
  - **Check inputs and logic**
    - Does the output of the model make physical sense?
      - Can we really build infrastructure in 2-3 yrs?
      - Is the labor estimate correct?
  - **Reexamine discounts & learning curves**
  - **Clean up the model to better match DCB needs**
- Incorporate a dynamic simulation of the process
  - **Create ramp ups and training curves**
- Want to continue to quantify the effect of various input changes and assumptions on the final cost estimate
  - Rent vs. Buy, raw material escalation, more or less cavity processing, cost versus fabrication time analysis, etc.
- Integrate input from US Industrial Studies
- Generate a solid Basis of Estimate
- Create a Dictionary to better define terms/acronyms



## U.S. Cost Estimate Conclusion

- Have gotten a good start on a cost model for cavities and cryomodules
  - **can vary key inputs and look at different scenarios**
- Model is quite inclusive and may need to get “trimmed back” as things become clearer
- Integration of cavity (JLab) and cryomodule (FNAL) costs is going well (weekly meetings)
  - **Need to communicate with SLAC on rf system model**
- **Although more work is needed, we’re optimistic that this model can play a role in helping to determine a U.S. cost estimate for the ILC**



# European Region Cost Estimate

- Cryomodule cost estimate based on original TESLA TDR numbers for the Type III+ design, and supplemented by the numbers for the XFEL



# Possibilities for Cost Reductions

- Cryomodule component-level cost reduction strategies
  - Separate cryostat for quad/corrector/bpm package (ACD item)
  - Incorporation of U.S. industrial cost study information may result in better cost numbers (hopefully lower)
- Cryomodule design-level cost reduction strategies
  - At the SLAC LCFoA meeting it was suggested that early involvement of industry in the design phase of the program might result in cost savings through design for manufacturability. We need to explore this fully.



# Towards the TDR

- Present cryomodule cost estimate based on the Type IV design
- Next generation CM design (Type V or ILC prototype) will incorporate design for manufacturability and cost reduction
- Efforts at industrialization must ramp up and involve more vendors in order to stimulate competition and perhaps lead to unit cost reductions