-A Satellite Workshop at IPAC-2010 -

Superconducting RF Cavity Technology and Industrialization

Industrialization Study with Japanese Industries

Eiji Kako (KEK)

in cooperation with Japanese Industries

IPAC-2010 Satellite Workshop, Kyoto, May 23, 2010

Outline

- Introduction
  - Industrial models assumed for the ILC SCRF cavities
- Industrialization Study in cooperation with Japanese Industries
  - Manufacturing process and facilities required
  - Industrial engineering examples

A Model for Industrialization

- A model for 9-cell cavity productions
  - 15,764 + spare + production back-up (~ 10%)
  - → ~ 18,000 cavities / 4~5 years

- Possible models for manufacturing
  - Single consortium/vendor
  - Three regional consortiums/vendors
  - Six (or more) consortiums/vendors
    - < 3,000 > cavities / vendor
    - < 3 > cavities / day / vendor

      (assuming 5 years and 200 days/year)

Industrialization Study in Japan

- KEK started the ILC industrialization study in cooperation with Japanese Industries

- KEK:
  - Provides process models and required times

- Industries:
  - Study manufacturing model and facilities required, and
  - Report examples of industrialization experiences as references for further studies

Standard process selected in cavity production and the yield

	Standard Cavity Recipe
Fabrication	Nb-sheet (Fine Grain)
	Component preparation
	Cavity assembly w/ EBW (w/ experienced venders)
Process	1st (Bulk) Electro-polishing (~150um)
	Ultrasonic degreasing with detergent, or ethanol rinse
	High-pressure pure-water rinsing
	Hydrogen degassing at > 600 C
	Field flatness tuning
	2nd Electro-polishing (~20um)
	Ultrasonic degreasing or ethanol
	High-pressure pure-water rinsing
	Antenna Assembly
	Baking at 120 C
Cold Test (vert. test)	Performance Test with temperature and mode measurement (1st / 2nd successful RF Test)

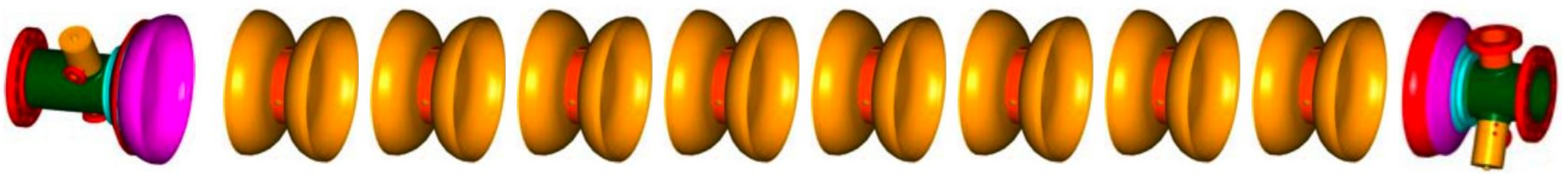
Example of cavity fabrication process

EBW of dumb-bell

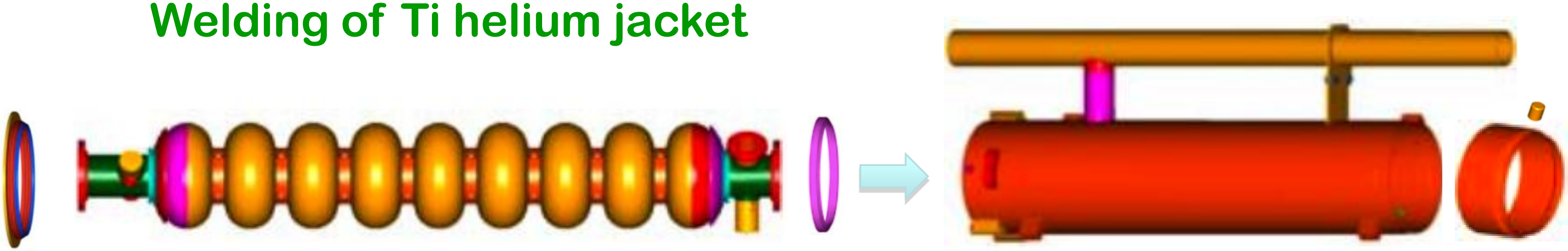
24 dumb-bells / day

EBW of 9-cell cavity

3 cavities / day



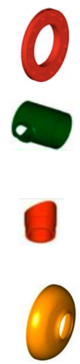
Welding of Ti helium jacket



3 cavities / day

Example of cavity fabrication process

Machining of end-group parts



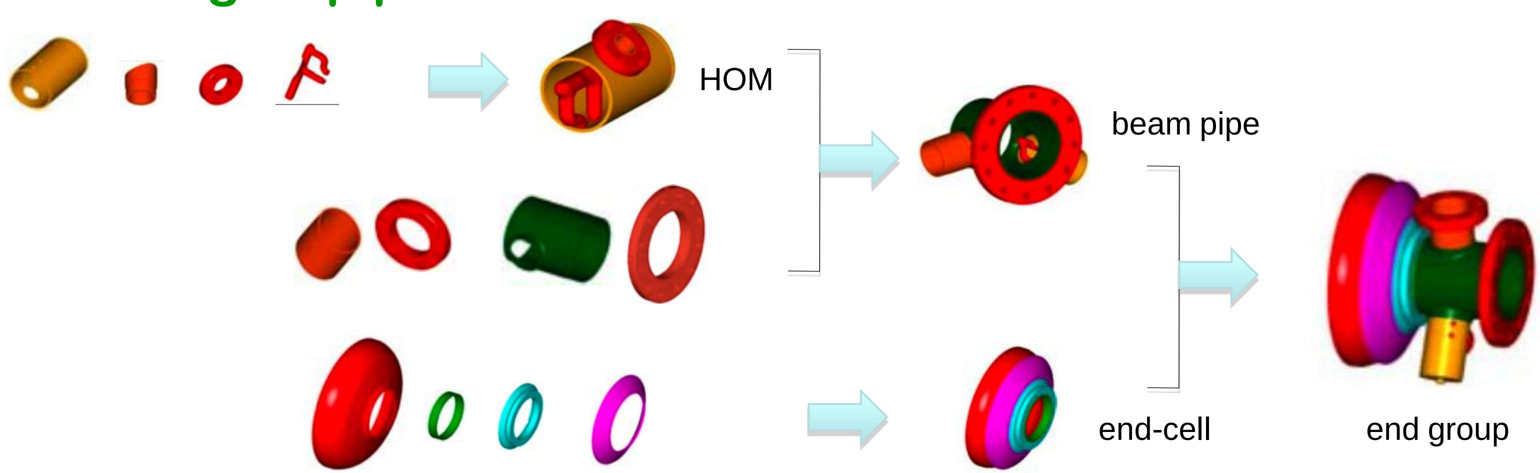
Nb-Ti flange (6/cavity) 18 / day

Nb beam tube (2/cavity) 6 / day

Burring of ports (4/cavity) 12 / day

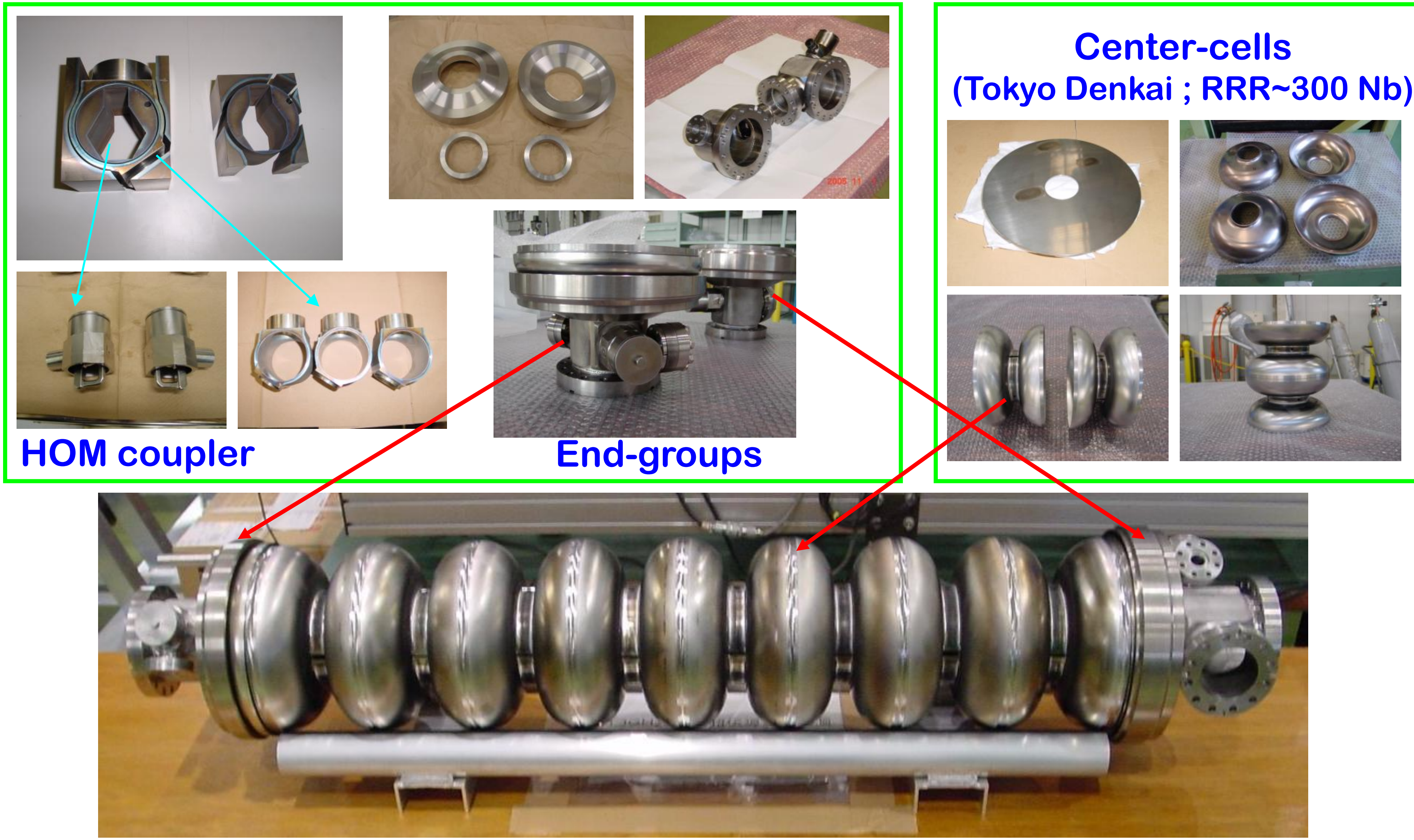
Trimming of half-cell (18/cavity) 54 / day

EBW of end-group parts

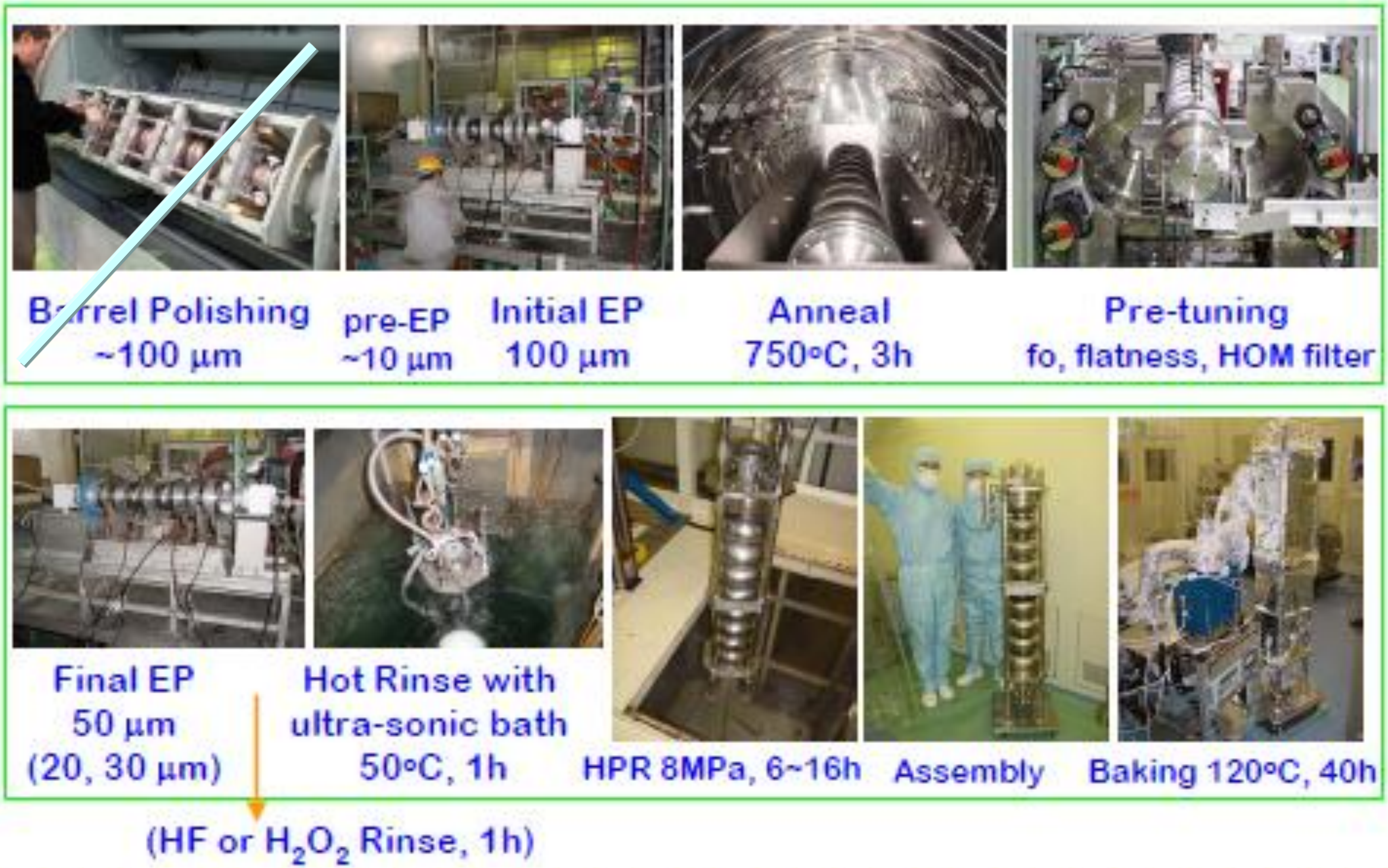


6 end-groups (both sides) / day

Cavity Fabrication Process



Cavity Processing for Vertical Tests



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Boundary Conditions

+ We evaluate an ideal production facility from cavity fabrication to cryomodule assembly to produce 600 cavities per year by using a factory production simulation analysis.

[assumption]

- Consider only process time including preparing time to machining, welding, vertical test, surface treatment and cryomodule assembly excluding time for conveying parts and assemblies.
- Assumed cavity yield at 35MV/m = 80% through first cavity processing and 50% after repairing and second cavity processing.
- Based on 16 hours of actual run time (2 shifts) per day for each machining and process.

- Evaluate the number of machines and apparatus to satisfy the production rate by use of production simulation code.
- Machining, welding and other process would use special jigs to handle multiple subassemblies for a given process cycle.

Mass Production Models

- **Case 1**
  - Laboratory R&D scheme
  - 1 seam / one welding cycle
- **Case 2**
  - Current production scheme at some industries
  - Dumb-bell: 8 seams / one welding cycle
  - 1 x 9-cell cavity EBW /one welding cycle
- **Case 3**
  - Simple mass production model
  - Dumb-bell: 8 seams / one welding cycle
  - 8 end-group / one welding cycle
  - 1 x 9-cell cavity EBW /one welding cycle
- **Case 4, (in Preparation)**
  - Dumb-bell: 8 seams / one welding cycle
  - 8 end-group / one welding cycle
  - 8 x 9-cell cavity EBW / one welding cycle

Cavity Fabrication

Nb sheets eddy current inspection — 15 min. / sheet

Half-cell deep drawing — 2 hrs / 60 cups

Half-cell trimming — 1 hour / cup

Half-cell geometry check — 5 min. / cup

Half-cell BCP for welds — 1 hour /16 cups

Dumb-bell EB welding
(1) 3 hours / dumb-bell
(2) 6.5 hours / 8 dumb-bells
(3) 6.5 hours / 8 dumb-bells

End parts stocked enough

End groups EB welding
(1) 11 hours / end group
(2) 11 hours / end group
(3) 47 hours / 8 end groups

9-cell cavity EB welding
(1) 9 hrs / 9 x one-cell
(2) 4.7 hrs / 1 x 9-cells
(3) 4.7 hrs / 1 x 9-cells

Cavity Processing

Numbers of processes trade-off

<table>
<tr><th rowspan="2"></th><th rowspan="2">Yield %</th><th rowspan="2">Fabrication of Dumb-bell with EBW</th><th rowspan="2">Fabrication of End group EBW</th><th rowspan="2">Assemble 9-cell Cavity With EBW</th><th colspan="3">Number of machines and processes required</th></tr>
<tr><th>EB Welding</th><th>Vertical Test</th><th>Electro-polishing</th></tr>
<tr><td rowspan="2">Case1
R&D phase</td><td>100</td><td rowspan="2">1 seam / welding cycle (3 hrs/3 cycle)</td><td rowspan="4">1 seam / welding cycle (11 hrs / 11 cycle)</td><td rowspan="2">one 2(4,8)-cell / welding cycle (9 hrs/9 cycle)</td><td rowspan="2">12</td><td>6</td><td rowspan="2">6</td></tr>
<tr><td>90</td><td>7</td></tr>
<tr><td rowspan="2">Case2
Current production</td><td>100</td><td rowspan="4">8 dumb-bell / welding cycle (6.5/8 hrs/3 cycle)</td><td rowspan="4">one 9-cell / 2 welding cycle (4.7 hrs / 2 cycle)</td><td rowspan="2">8 → 7*</td><td>6</td><td rowspan="2">6</td></tr>
<tr><td>90</td><td>7</td></tr>
<tr><td rowspan="2">Case3
Mass Production Study</td><td>100</td><td rowspan="2">8 end-group / welding cycle (46.7/8 hrs/11 cycle)</td><td rowspan="2">5 → 4*</td><td>6</td><td rowspan="2">6</td></tr>
<tr><td>90</td><td>7</td></tr>
</table>

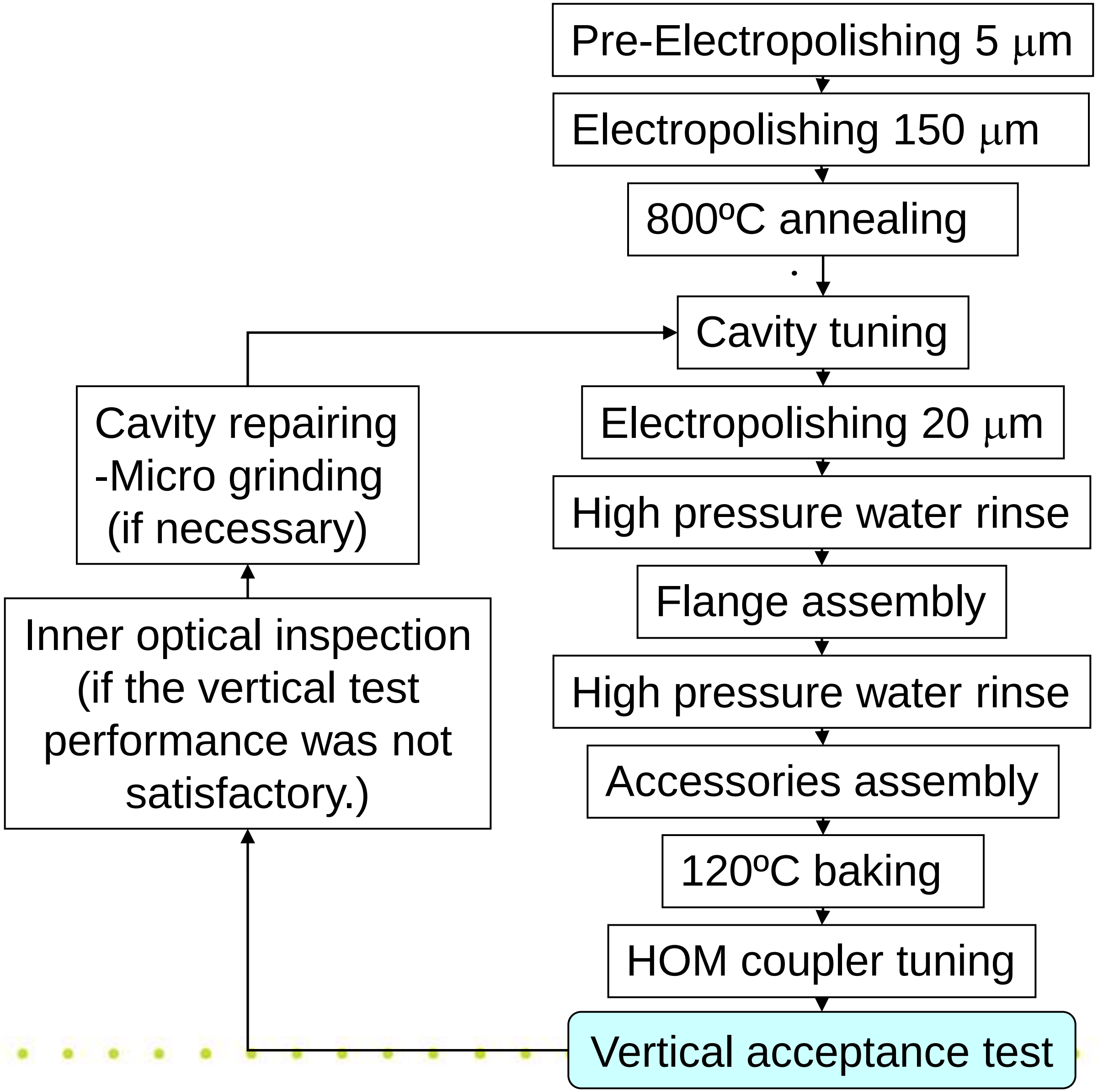
*** In case of common EBW machines for dumb-bell and end-group**

Number of Cavity Fabrication Facilities Required

	actual run time (2 shifts) per day for each process	Number of machines (processes)					
		Case1		Case2		Case3	
		Yield %					
		100	90	100	90	100	90
Nb sheets eddy current inspection	16	1	1	1	1	1	1
Half-cell deep drawing	8	1	1	1	1	1	1
Half-cell trimming	16	3	3	3	3	3	3
Half-cell geometry check	8	1	1	1	1	1	1
Half-cell BCP for welds		1	1	1	1	1	1
Dumb-bell EB welding	16	5	5	2*	2*	2**	2**
End groups EB welding		5	5	5*	5*	2**	2**
9-cell cavity EB welding		2	2	1	1	1	1

*** 2+5 →6, ** 2+2 →3**
in case of common EBW machine

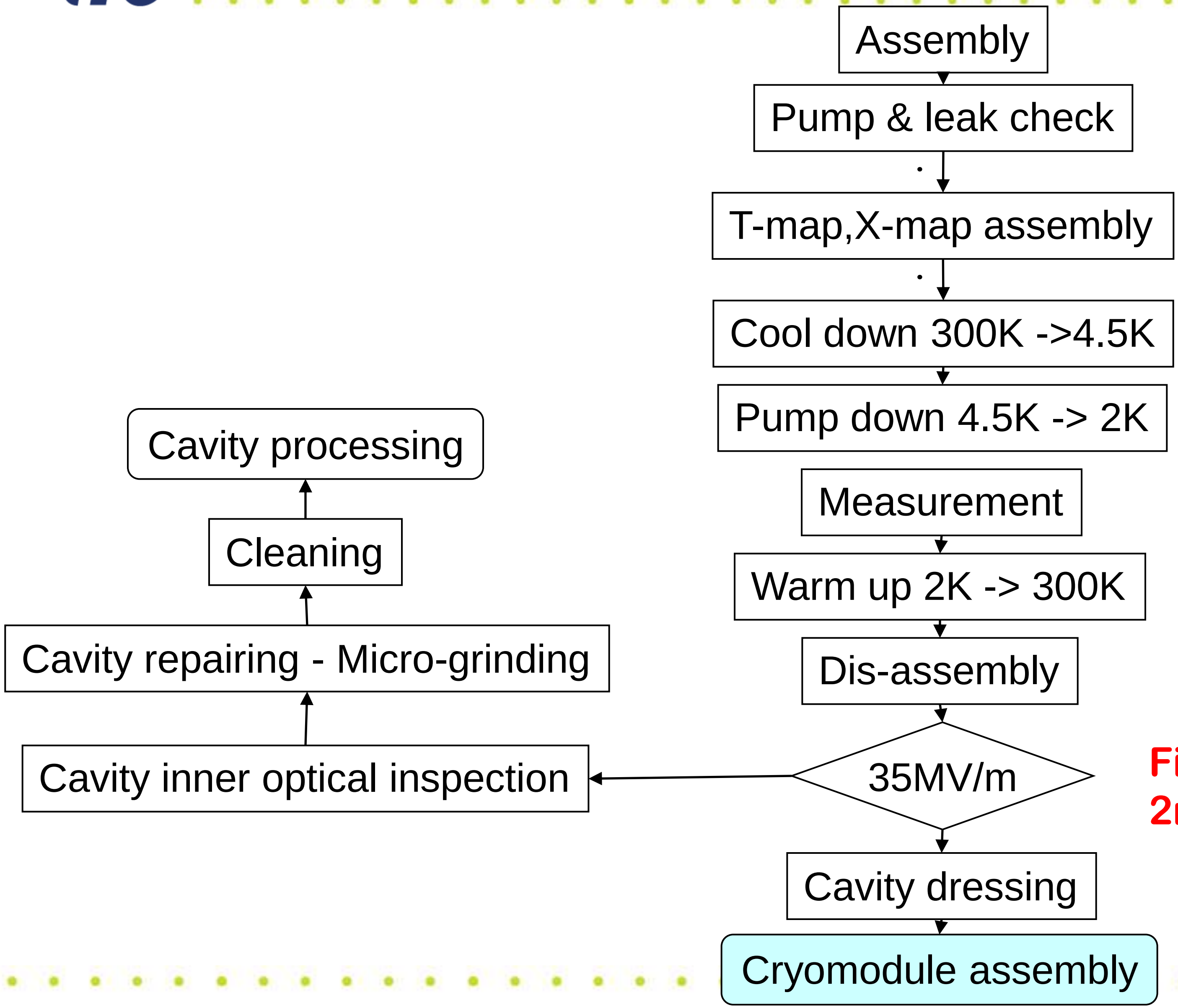
Cavity Processing



Cavity Processing

	actual run time (2 shifts) per day for each process	Number of machines (processes)					
		Case1		Case2		Case3	
		Yield %					
		100	90	100	90	100	90
Pre-Electropolishing	16	2	2	2	2	2	2
Electropolishing 150 μm		6	6	6	6	6	6
Electropolishing 20 μm							
800ºC annealing	24	2	2	2	2	2	2
Cavity tuning	16	2	2	2	2	2	2
Flange assembly	8	1	1	1	1	1	1
High pressure water rinse	16	2	2	2	2	2	2
Assembly of accessories		2	2	2	2	2	2
High pressure water rinse		2	2	2	2	2	2
120ºC baking	24	2	2	2	2	2	2
HOM coupler tuning	16	1	1	1	1	1	1

Vertical Acceptance Test

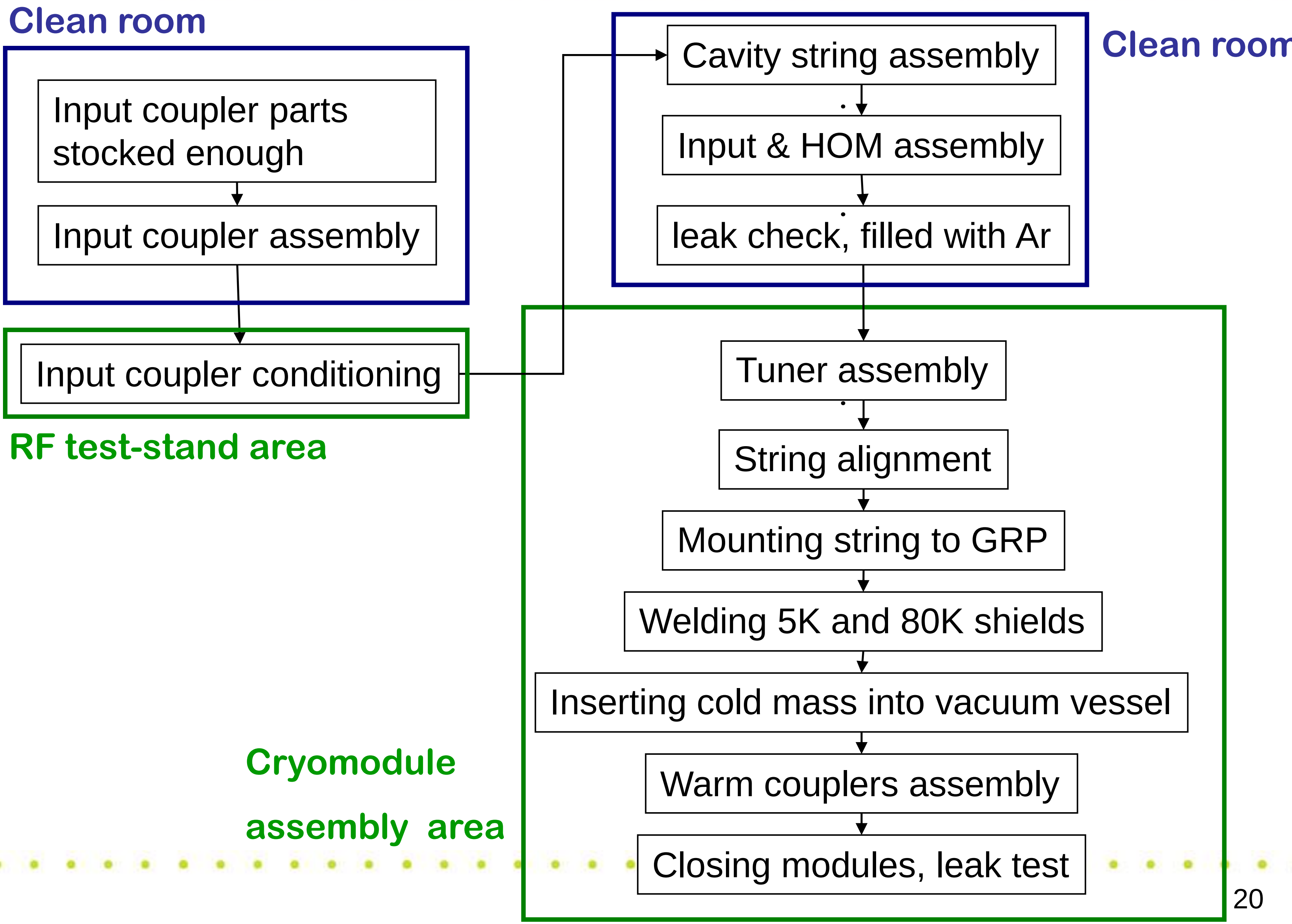


First test: yield 80%
2nd test: yield 50%

Vertical Acceptance Test

	actual run time (2 shifts) per day for each process	Number of machines (processes)					
		Case1		Case2		Case3	
		Yield %					
		100	90	100	90	100	90
Assembly	16	2	2	2	2	2	2
Pump & leak check							
T-map,X-map assembly							
Cool down 300K ->4.5K		6	7	6	7	6	7
Pump down 4.5K -> 2K							
Measurement							
Warm up 2K -> 300K							
Disassembly		1	1	1	1	1	1
Cavity inner optical inspection	8	1	1	1	1	1	1
Cavity repairing - Micro-grinding	16	1	1	1	1	1	1
Cleaning	8	1	1	1	1	1	1

Cryomodule Assembly



Cryomodule Assembly

<table>
<tr><th rowspan="4"></th><th rowspan="4">actual run time (2 shifts) per day for each process</th><th colspan="6">Number of machines (processes)</th></tr>
<tr><th colspan="2">Case1</th><th colspan="2">Case2</th><th colspan="2">Case3</th></tr>
<tr><th colspan="6">Yield %</th></tr>
<tr><th>100</th><th>90</th><th>100</th><th>90</th><th>100</th><th>90</th></tr>
<tr><td>Cavity dressing</td><td rowspan="13">16</td><td>5</td><td>5</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>Cold coupler assembly</td><td>5</td><td>5</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>Input coupler conditioning</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td>String assembly</td><td rowspan="3">1</td><td rowspan="3">1</td><td rowspan="3">1</td><td rowspan="3">1</td><td rowspan="3">1</td><td rowspan="3">1</td></tr>
<tr><td>Input & HOM assembly</td></tr>
<tr><td>leak check, filled with Ar</td></tr>
<tr><td>Tuner assembly</td><td rowspan="7">4</td><td rowspan="7">4</td><td rowspan="7">4</td><td rowspan="7">4</td><td rowspan="7">4</td><td rowspan="7">4</td></tr>
<tr><td>String alignment</td></tr>
<tr><td>Mounting string to GRP</td></tr>
<tr><td>Welding 5K and 80K shields</td></tr>
<tr><td>Inserting cold mass into vacuum vessel</td></tr>
<tr><td>Warm couplers assembly</td></tr>
<tr><td>Closing modules, leak test</td></tr>
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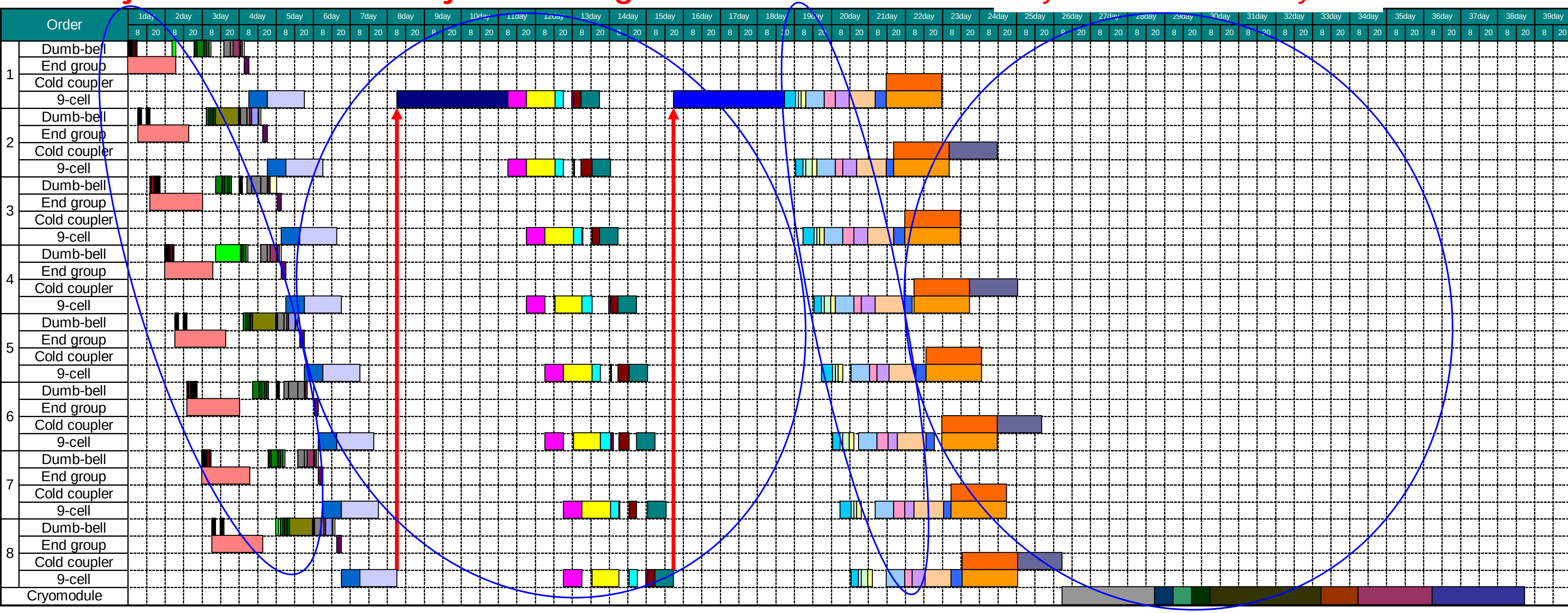
Example of Production Process (Case1)

Cavity Fabrication Cavity Processing Vertical Test Cryomodule Assembly



- Nb sheets eddy current inspe
- Half-cell deep drawing
- Half-cell trimming
- Half-cell geometry check
- Half-cell BCP for welds
- Dumb-bell EB welding
- 9-cell cavity EB welding
- 9-cell cavity EB welding
- 9-cell cavity EB welding
- 9-cell cavity EB welding
- End groups EB welding

- Pre-Electropolishing
- EP110mm
- 800ºC annealing
- Cavity tuning
- EP40mm
- HPR
- Flange assembly
- HPR
- Assembly of accessories
- 120ºC baking
- HOM coupler tuning

- Assembly
- Pump & leak check
- T-map,X-map assembly
- Cool down 300K ->4.5K
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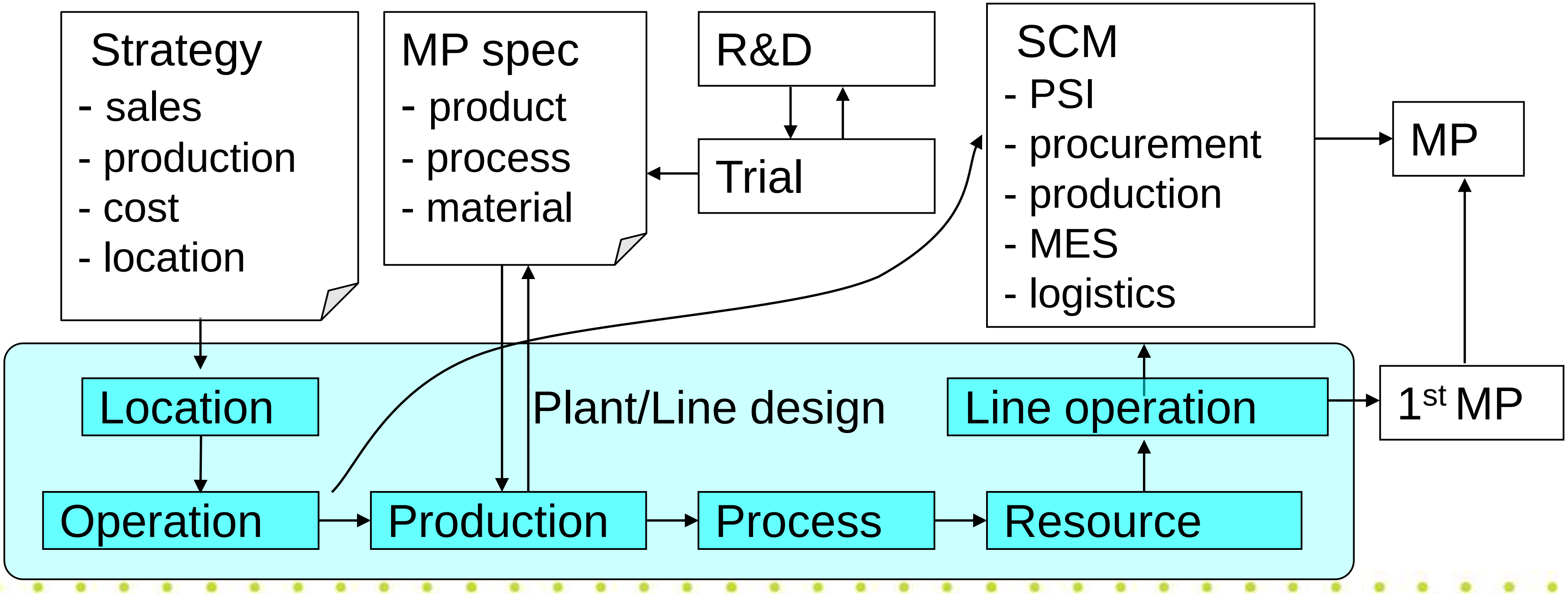
Mass Production
Engineering Experience

1. Basic method for Mass Production line design
2. Example Mass Production line design like ILC
3. Consortium Experience with SELETE

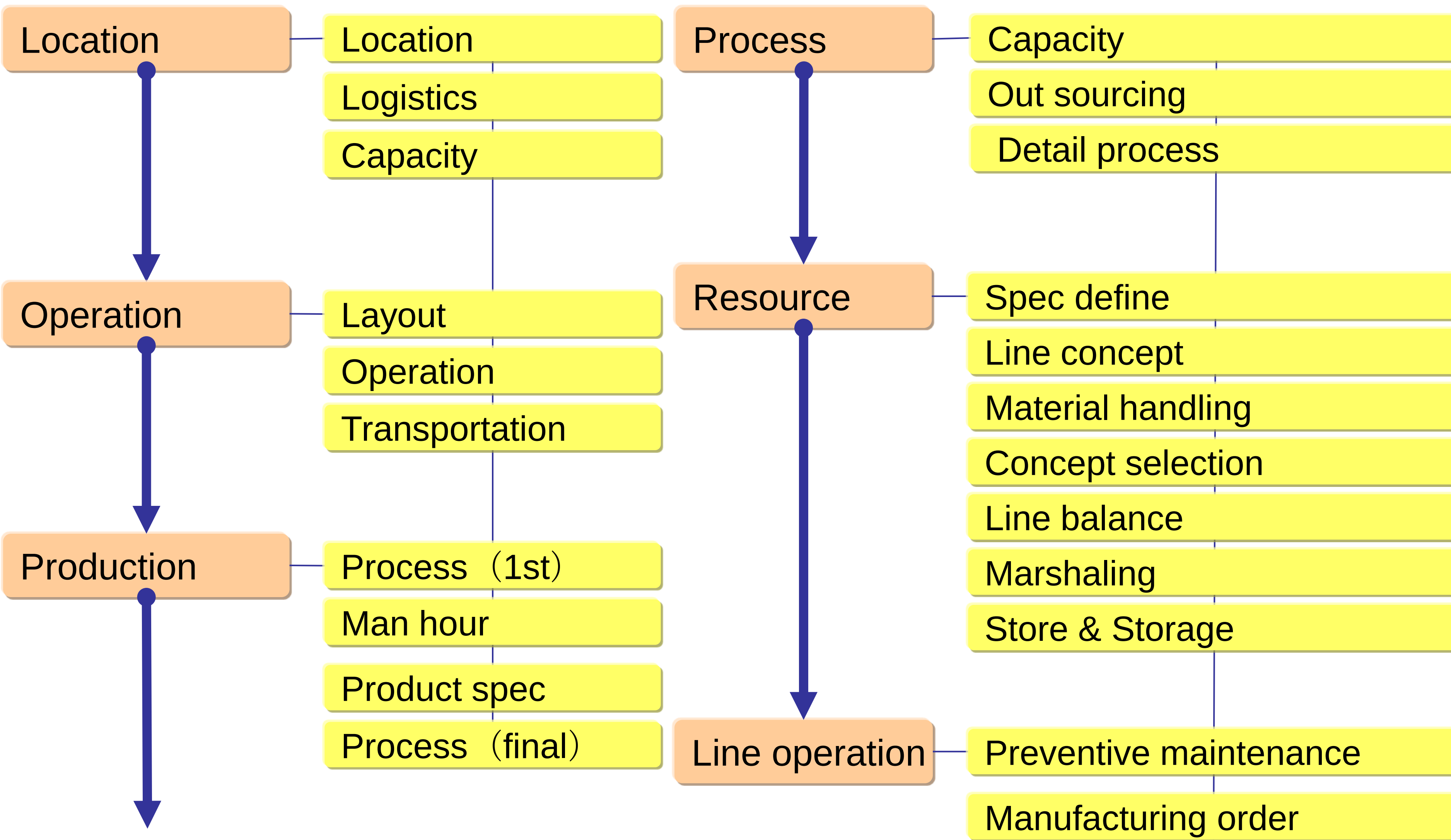
Basic method for Mass production line design

- Start line: Outline of MP spec finished
- Objective: Cost (Equipment investment, labor cost) and delivery (lead time)
- KPI:
  - Quality
  - Cost ⇒estimate on cost simulation
  - Delivery⇒ estimate on manufacturing simulation
- Cycle time: 2 minutes(= 200p / 8 Hr)
- Motif: Semiconductor, LCD, HDD
- Production term: many production model

PSI: Purchase & Production, Sales, Inventory
MES: Manufacturing execution system
SCM: Supply chain management



Basic method for Mass production line design



Example of Mass production line of new product

■ Abstract

- Product: Electrical control unit
- Amount: 100Kp/Y
- Investment: 500million yen
- Sales Price: 100k yen
- Customer: USA
- Return term: 5years

■PJ

PJL,SPJL

Steering committee
- Committee:1time/M
- Confirmation of status
- Confirmation of problem

MP line WG
- Process planning
- Development of Equipment
- Equipment investment plan

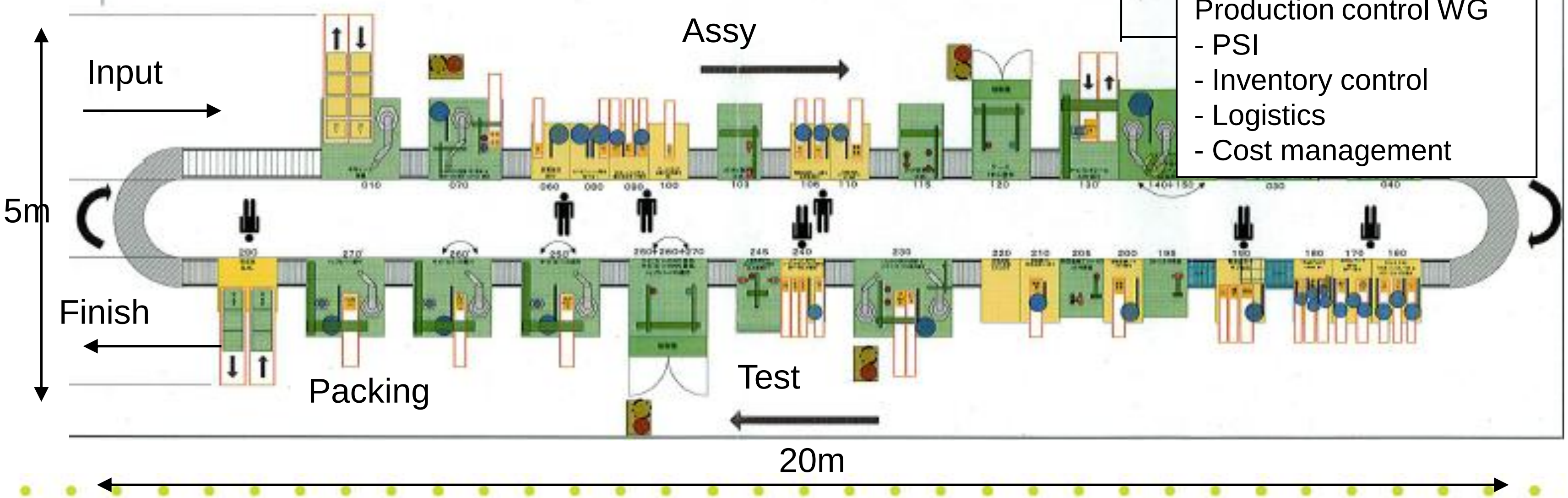
QC WG
- Traceability system
- QMS
- Process QC

Procurement WG
- CR
- Select of supplier

Production control WG
- PSI
- Inventory control
- Logistics
- Cost management

QMS: Quality management system
QC: Quality control
CR: Cost reduction

■ MP line idea



SELETE as a Consortium

Semiconductor Leading Edge Technologies,Inc.

SELETE was founded in 1996 as a consortium for development of production technologies using 300mm wafer equipments with equal capital investment from 10 semiconductor manufacturers.

FUJITSU、HITACHI、MATSUSHITA 、MITSUBISHI、NEC、OKI 、SANYO、SHARP、SONY、TOSHIBA

Investment（ 500 million yen each company)

- **Objective:**

Reduce of R&D cost for higher difficulty and R&D cost of semiconductor technologies

- **Target :**

Evaluation and improvement for 300 mm wafer mass production equipment.

- **Output:**

Evaluate 137 equipments necessary to all production technologies for 300 mm mass production plant.
Equipment performance target unify to International Sematech(I300I).

SUMMARY

- ILC cavity industrialization models have been investigated in cooperation with Japanese Industries,
  - A production model: 3 cavities/day for 5 years
- Based on each process time determined by KEK, the required industrial facilities have been investigated,
- Dumb-bell process may be a critical pass to determine number of EBW facilities, and multiple seams per one welding cycle may help to reduce the number of EBW facilities,
- Full production model in preparation to be studied,
- Workshop layout and number of workers are to be further studied, as well as the cost-effective fabrication is to be investigated.

Acknowledgements

- *We would thank*
  - Japanese industries (MHI, Toshiba, and Hitachi) manufacturing SCRF cavities for their kindest cooperation for the industrialization studies.