Recent milestones:
- December 23, 2008:
  - 30 GeV beam acceleration and fast extraction to the beam abort dump
  - MLF user run (20kW)
- January 27, 2009:
  - Beam extraction to the Hadron Experimental hall using slow beam extraction system
- February 19, 2009:
  - Government inspection for radiation safety
Beam commissioning has been accomplished on schedule, BUT without space charge effect.

We should understand its significance, BUT should not overestimate.

Real challenge toward the power frontier machine will start from now on.

- We still have many issues (unreliable components, design etc.) to be solved.
- At the same time, we have to provide the beam to users (It’s a duty) (MLF, Hadron, Neutrino).
- Additionally, power upgrade should be also accomplished steadily.
Goal (Mission) and Issues for 3-step Power Upgrade Scenario

- **100kW trial in JFY2009**
  - JFY2009 Schedule
  - RCS status and plan for MLF user run (Michikazu Kinsho)
  - MR commissioning status (Tadashi Koseki)
  - Urgent issues to be solved
    - RFQ
    - MR Magnet power supply

- **Beyond 100kW from 2010: 100➡750kW (Design)**
  - Space charge effect and collimator scenario
  - Linac 400 MeV energy recovery and upgrade of the RCS injection system

- **Long-term plan toward power frontier (~MW)**
  - KEK roadmap
Tentative plan for MLF user run and MR run in JFY2009

- **MLF User run:**
  - 110 days

- **Linac operation total:**
  - 190 days

- **3-Month Summer shutdown:**
  - July~September

- **MR operation schedule:**
  - Tentative !!!

**MR operation includes:**
- Commissioning
- Power Improvement
- User Run
Tentative RCS power up grade plane
for MLF User Run (NOT for MR)
considering the lifetime of mercury target

We need discussions

Michikazu Kinsho
MR commissioning status

MR beam commissioning schedule

1st stage (May 2008-June 2008):
Available dump is the injection beam dump.
Beam transport of 3-50 BT, injection, closed orbit, rf capture,
extration to beam dump at 3GeV.

Installation of FX and SX components/
(July 2008-Nov. 2008)
FX septa (SM1,2, SM33), FX kickers,
SX devices,
neutrino beamline components,
tuning of main magnet power supplies,
change the cabling of main B/Q magnets.

The dumps at the abort beamline and HD beamline are available.
Acceleration from 3 to 30 GeV,
Fast extraction to abort line,
Slow extraction to hadron beamline.

3rd stage (April 2009 - June 2009):
The dump at the NU beamline is available.
Fast extraction to neutrino beamline.
<table>
<thead>
<tr>
<th></th>
<th>JFY2006</th>
<th>JFY2007</th>
<th>JFY2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3</td>
<td>4 5 6 7</td>
<td>8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3</td>
</tr>
<tr>
<td>Linac</td>
<td></td>
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<td></td>
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<tr>
<td>RCS</td>
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<td></td>
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<tr>
<td>MR</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1st stage</td>
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<td></td>
<td></td>
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<tr>
<td>2nd stage</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3rd stage</td>
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<tr>
<td>MLF</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Hadron</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutrino</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Beam**: Red
- **Installation / Off beam commissioning**: Yellow
- **Building construction**: Grey
- **Start of off beam commissioning**: Star
- **Government inspection of PPS**: Up triangle
- **Government inspection of radiation shield under beam operation**: Down triangle

1st stage
↓
Summer shutdown
↓
2nd stage
↓
3rd stage
Fast extraction tuning

No losses during acceleration
- Imaginary $\gamma_1$
- Precise control by digital LLRF
- Untuned cavity with low Q value
Slow extraction operation

Slow extraction:
- Bump magnets ON
- Resonant sextupoles ON
- Tune ramp pattern for QFN: (22.30, 20.76) -> (22.35, 20.76)

It's a "Ripple extraction" using SX system
We need:
- further improvement of magnet power supply
- installation of feedback system

Beam intensity during extraction

Steps

Spill measurement in HD beamline

RF off, $\xi$$\sim$0

RF off, $\xi$$\sim$-2
Beam loss study for SX

Beam loss in the SX operation

Distribution of integrated counts of the BLMs signal

Time dependence of the BLM signals
Calibration of Beam Loss & Residual Radiation Level @ 30 GeV Resonance Extraction

- **(1/6) Hz Test Operation**
  - BLM: Max. 2500 Counts / Position ----> 2.0E9 protons
  - 17000 Counts / Total 1.4E10
  - Accelerated: 1.3E11 protons/6 sec (100 W)
  - Extraction Efficiency: ~ 90 %
  - Max. ~ 1.6 W Loss @ Each Position
  - ===> Residual: 23 μSv/h Max.
  - < 1 mSv/h
  - < 70 W (Loss/SX area)

Calibration of Beam Loss Monitor
@ 30 GeV Slow Extraction / 2009. 02. 14

\[
y = a^*(\text{Count})
\]

<table>
<thead>
<tr>
<th>Value</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>8.0515e-5</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>0.98109</td>
<td></td>
</tr>
</tbody>
</table>
Guide-line for allowable beam loss \textit{at this moment} upper limit < 25W/SX Area & ALARA (As Low As Reasonably Achievable)

\begin{itemize}
\item 25W loss
\item 333\(\mu\)Sv/h
\end{itemize}

Radiation Maintenance \(\text{@ ISIS}\)

February 2009:
100W/10W loss \(\rightarrow\) 90\% extraction eff.
\(\rightarrow\) 250W/25W loss

Extraction Efficiency should be upgraded to obtain higher beam power
500W/25W loss \(\rightarrow\) 95\% (BNL Achievement)
2.5kW/25W loss \(\rightarrow\) 99\%
\(\sim\) 10kW will be coming within the range

Only way to achieve the beam power of 100kW-class SX,
1. improve the extraction efficiency more and more,
2. beam loss should be localized at the ESS and 2\textsuperscript{nd} collimator, and
3. radiation maintenance technology should be developed.
Plan of MR 100 kW trial in FY2009

1st Quarter: April, May, June
- Fast extraction: establish neutrino primary beam line orbit
- Hadron hall: Construction of secondary beam lines

2nd Quarter: July, August, September - Machine Shutdown
- Installation of EQ and RQ for spill control
- Maintenance and/or upgrade of troubled components
- Neutrino Target Station (Installation of horn #2&3 from July)

3rd Quarter: October, November, December
- FX: Power upgrade
- SX: Spill control and power upgrade by reducing beam loss

4th Quarter: January, February, March
- FX: Power upgrade toward 100 kW (for $10^7$ sec)

EQ: Extraction Q to shape up the spill time structure,
RQ: Ripple Q to reduce ripple structure
RFQ problem

Discharge problem in the RFQ limits both beam power and availability.
Prototype RFQ (same design)

Observation of vanes by a scan electron microscope (SEM). (X500)

Can be seen machining lines by tool, but few discharge sign.
Electromagnetic analysis

Analysis of multipacting

Result:
- Vane-tip, PISL-hole: discharge
- PISL and wall: multipacting

"TE210" mode
(d=2m, 两端磁気的短絡)

Electric field strength at PISL-hole is rather high, 60-70% of vane tips.

Color change to black at the tuner and wall
Color change to white around the PISL

multipactating
Summary

Current RFQ should be used (alive) at least one and half year.

We should
- operate at a minimum risk,
- have conditioning if needed, handle with care, and
- take action as soon as possible, improvement of vacuum, etc.

Design and construct a backup machine as soon as possible
- Key word: stable operation
- Investigation of disorder and reflection to design work
- Construction
- Standing by after the RF conditioning
- Replacement

RFQ-BUG (back up group)
- Leader: Hasegawa, Yoshioka
- RF-design: Kondo, Morishita, Naito, Yamaguchi
- Vacuum, Structure: Saito, Hori, Matsumoto, Kawamata
- Some specialists
MR magnet power supply problems

Direct frequency conversion from 22kV commercial AC line using IGBT/IEGT switching unit

Normal mode reactor
Passive filter
Active filter

Not established technology but world first challenge

Current status:
Ripple, low repetition rate and poor availability

Catch-phrase of the ambitious design:
- Compact
- High-efficiency
- Power factor=1
- Low noise

Risks:
Large switching noise from IGBT ➔ delicate control ➔ low repetition rate
Fragile IGBT ➔ poor availability

No neutral line (point)
No symmetric circuit ➔ large common mode noise ➔ ripple
How to solve problems?

- Add more filter and choke both for normal and common modes
- Reduce ripple from $10^{-4}$ to $10^{-5} \sim 10^{-6}$ and recover better control
- Remodel (improve) for symmetric circuit not only for power cable configuration but also circuit itself

Ultimate goal of the repetition rate $\rightarrow 0.5\text{Hz}$
Scenario beyond 100kW

100→750kW (Design)

Main issue is the Space Charge Effect
We have only three knobs for this problem;
- Collimator scenario to cut beam halo
- Enough aperture
- Bunching factor
  (RF fundamental-mode + Higher Harmonic cavities)

Another parameter, which is independent from space charge effect
→ increase repetition rate
  (magnet power supply issue)

- Receive beam from RCS as much as possible, and
- Accelerate and extract the beam with minimum loss as quick as possible.
Current bottleneck
- Poor collimator capacity
- 450W
- Small fast extraction aperture

Rely on the adiabatic
Damping at RCS and
MR @50 GeV

Emittance \( \sim (By)^{-1} \)
\[
\Delta v = \frac{n_l r_p}{2\pi B_j} \frac{1}{\beta_0^2 \gamma^3}
\]

ATAC06, 07, 08: Alexander Molodozhentsev
Simulation results suggested insufficient power capacity of both 3-50BT and ring collimators.
**MR:** TOTAL lost beam power for basic MR operation scenario

- Beam power from RCS is \(300\,\text{kW}\)
  (~1.8 kW/bunch at 3 GeV for MR)
- 8 bunches operation scenario
- Jaw of the beam line collimator is \(54\,\pi\)
- MR RF system: \(V_{RF} = 210\,\text{kV}\) (h=9) ... 'constant' mode
- \textbf{Wp\#14:} \(Q_x = 22.318 / Q_y = 20.87\) with full chromaticity correction
- 10\% of the transverse beam mismatching
- MR Scraper Aperture = \(60\,\pi\)
- Without any resonance correction for Wp\#14

Total power of the lost beam \(\approx 240\,\text{W} + 90\,\text{W} \approx 330\,\text{W}\)

Injection  Acceleration

Alexander Molodozhentsev (KEK)
Detuning effect of the low energy space charge for J-PARC Main Ring

'Bare' working point:
\[ Q_{x0} = 22.428 \] 
\[ Q_{y0} = 20.824 \]

Beam power = 1.8kW/bunch
(300kW from RCS)
30% of design value

Bunching factor ~ 0.2
Chamber size = ± 70 mm

Beam power = 3.6kW/bunch
(600kW from RCS)
60% of design value
Particle losses during the injection process @ scraper

**Estimation of the lost beam power at MR scraper (wp#2)**

<table>
<thead>
<tr>
<th>Machine condition</th>
<th>Lost beam power [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR_Scr = 54π TR_matched</td>
<td>~ 400</td>
</tr>
<tr>
<td>MR_Scr = 60π TR_matched</td>
<td>~ 128</td>
</tr>
<tr>
<td>MR_Scr = 54π TR_MisMatched</td>
<td>~ 850</td>
</tr>
<tr>
<td>MR_Scr = 60π TR_MisMatched</td>
<td>~ 440</td>
</tr>
</tbody>
</table>

Particle losses during the full injection process (~120 msec) for the realistic machine parameters for the beam power of 1.8kW/bunch. (30% of design value)

- The MR scraper acceptance is 54 π mm.mrad.
- Wp#2: 22.30 / 20.92 to avoid 3Q_x resonance.
- V_RF = 40kV (fundamental harmonic)

- 4 batches operation (h=9)
- TR_MisMatched -> 10% beta-mismatching
Particle losses during the acceleration process

Emittance is growing up to 7 GeV and loss is increasing

Particle losses during the acceleration for the RF pattern (40kV → 280kV). MR_Scraper acceptance = 60 \pi

Initial mis-matched beam (10% beta mismatching).

Estimation of the 99.9% emittance after acceleration

\[ W_{\text{kin}} = 40 \text{GeV} (\beta \gamma = 43.62): \]

\[ \varepsilon_{\text{NORM}} (\text{MAX}) \approx 400 \pi. \]

Then \( \varepsilon_{99.9\%} \) for 40GeV beam \( \approx 9.2 \pi \)
3-50BT Collimator section is located under the public road “HAKKEN DORO” (between the Shrine and sea shore)
Our baseline scenario to solve the collimator problem → develop 5 kW-class collimators and replace them as early as possible
2nd generation fast extraction devices should be developed and several Q-magnet aperture should be improved to obtain enough aperture at 30 GeV.
Scenario to achieve the design beam power (750kW) @ 30 GeV

In order to increase the RCS bunch current, RCS harmonic number should be 1 instead of 2

Risks:
- RCS cycle for MR injection: 120 → 240msec
- Space charge force increases

Necessary baseline condition:
- New collimator of 5kW-class capability
- Enough aperture
Long-term plan
toward MW-class power frontier
KEK roadmap
KEK Roadmap (July, 2007: KEK Roadmap Panel led by F. Takasaki)

- J-PARC: construction
- KEKB: 1 (ab)^{-1} (operation & completion of 1st goal, power upgrade, upgrading to Super-KEKB)
- Photon Factory: operation & upgrade
- ERL R&D: continue R&D and compact ERL
- LHC: continue R&D, 1st results, operation, LHC upgrade
- ILC R&D: EDR
Plan for Improving Neutrino Beam Intensity by Main-Ring Upgrade

Linac: 181 MeV to 400 MeV

- 0.60 MW → 0.91 MW
- 0.28 Hz → 0.57 Hz
- 1.66 MW
- 0.52 Hz

- RF system improvement
- BM power supply

- Shorten acceleration time
- More RF system
- Magnet power system

- More beam per pulse
- Operation of 3 GeV RCS in harmonic number = 1
If we can receive more RCS beam power than 500 kW, we can obtain higher power than 750 kW.

Extensive studies are necessary;
- Increase MR repetition rate,
- Understand space charge effect,
- Develop collimator and aperture scenario.
Summary

Neutrino
1. Early achievement of 100kW run (for $10^7$ sec)
2. Create strong team to consider and work for the power upgrade scenario from 100 to 750kW.
3. The above second step should be the base of the MW-class power frontier machine.

Hadron
1. Early realization of spill control by;
   1. improving magnet power supplies, and
   2. applying feedback system.
2. Early achievement of 10kW-class power by;
   1. understanding and suppressing and/or localizing the beam loss.
3. In order to realize 100kW-class slow beam extraction, we have to develop;
   1. excellent extraction efficiency,
   2. more beam loss control, and
   3. radiation maintenance technology.
Backup slides
# Issues for RCS power upgrade

<table>
<thead>
<tr>
<th>Date</th>
<th>Beam Condition</th>
<th>Required items</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008.12-</td>
<td>20 kW; 5mA/0.1ms/560ns</td>
<td></td>
</tr>
<tr>
<td>2009.05-</td>
<td>20 kW; 5mA/0.1ms/560ns</td>
<td>• Reduction of injection loss</td>
</tr>
<tr>
<td></td>
<td>20 kW; 5mA/0.17ms/560ns</td>
<td></td>
</tr>
<tr>
<td>2010.10-</td>
<td>50 kW; 15mA/0.50ms/560ns</td>
<td>• Cure for foil-scattering loss</td>
</tr>
<tr>
<td></td>
<td>100 kW; 10mA/0.50ms/560ns</td>
<td>• AC power supply for chromatic correction sextupoles</td>
</tr>
<tr>
<td></td>
<td>200 kW; 15mA/0.50ms/560ns</td>
<td>• 11 sets of RF cavities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• New RFQ</td>
</tr>
<tr>
<td>2011-</td>
<td>100 kW; 15mA/0.50ms/560ns</td>
<td>• 12 sets of RF cavities</td>
</tr>
<tr>
<td>2013-</td>
<td>200 kW; 15mA/0.50ms/560ns</td>
<td>• 300 MeV injection (E_{\text{inj}}=300 \text{ MeV} \quad (\beta^2 \gamma^3)<em>{300}/(\beta^2 \gamma^3)</em>{181}=1.94)</td>
</tr>
<tr>
<td>2014-</td>
<td>200 kW; 15mA/0.50ms/560ns</td>
<td></td>
</tr>
<tr>
<td>2015-</td>
<td>200 kW; 15mA/0.50ms/560ns</td>
<td>• 400 MeV injection (E_{\text{inj}}=400 \text{ MeV} \quad (\beta^2 \gamma^3)<em>{400}/(\beta^2 \gamma^3)</em>{181}=2.92)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• RCS injection system for 400 MeV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• injection bump, paint bump, and …</td>
</tr>
</tbody>
</table>
Beam parameters of Linac and RCS for MR commissioning

Linac: Peak=5 mA, Pulse width=0.1 msec, chopping width =100/140/280 nsec,
RCS: Single bunch (4e11pb, ~1% of design goal), estimated emittance ~15 πmm.mrad

20% of normal width due to RFQ problem

Beam switching between MR and MLF using pulse bend magnet has been ON since last December.

To MR: single shot, 0.167 Hz (for 30 GeV)

To MLF

Simultaneously operation with MLF

6 second cycle due to magnet power supply problem

Operation modes of MR
- Injection dump mode: Injection beam is directly extracted to injection beam dump without circulation (useful for initial tuning of 3-50 BT and injection devices)
- 3GeV storage mode: Beam is stored and extraction to injection beam dump without acceleration (typical storage times are 100 turns, 1000 turns, 1 sec.)
- Abort dump mode: Beam is accelerated to 30 GeV and extracted to abort beam dump using the fast extraction system
- SX mode: Beam is accelerated to 30 GeV and extracted to HD beam line using the slow extraction system

Design repetition is 3.64 sec

Bending magnet pattern for abort dump and SX modes

<table>
<thead>
<tr>
<th>Kinetic Energy [GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
</tr>
<tr>
<td>30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time [sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
</tr>
</tbody>
</table>

Acceleration: 2.5 sec
Flat top: 0.7 sec
Repetition: 6 sec
The first stage of MR beam commissioning has been started on May 19, 2008.

**RUN #16:** May 19-24 (6 days)
- May 19: Beam was transported from the RCS to the MR injection Kickers
- May 20: First beam circulation without rf capture
- May 22: 1000 turns circulation with rf, beam extraction to the injection beam dump
- May 23: Circulation for one sec, continuous operation of 3 GeV storage mode with 3.64 sec

**RUN #17:** June 14-21 (8 days, but time shared with the MLF for 4days)
- June 19: Government inspection of radiation shield under operation of 3 GeV storage mode.

Total operation time ~ 12 hours*12 days.

**Improvement of BM Power Supply:** BL ripple was improved drastically by adopting symmetrical power cable configuration between the power supply and the magnet

- **April 2008**
- **September 2008**

**Current ripple**

Drastic improvement

**Details** ➔ see previous PAC talk by A. Ando

Serious problems of MR magnet power supply were found.

The half year operation of quick and “crazy” work has been carried out!

**Improvement of**
- Power supply itself, and
- Power cable configuration
Improvement of ripple problem

Horizontal tune fluctuation at 3 GeV

Vertical tune fluctuation at 3 GeV

Tune survey

3 GeV storage mode
Outline and achievements of the 2nd stage of Beam commissioning

The second stage has been started on Dec.22, 2008.

**RUN #20**: Dec. 22-25 (4 days)
- Dec 23: Acceleration from 3 GeV to 30 GeV and beam extraction to the abort beam dump using the fast extraction system.

**RUN #21**: Jan. 19-30 (12 days)
- Jan 27: Beam extraction to the hadron beam dump using the slow extraction system.

**RUN #22**: Feb. 10-15, 17-20 (10 days)
- Feb 12: Continuous operation with 6 sec period for SX mode.
- Feb 13: Continuous operation with 6 sec period for abort dump mode.
- Feb 19: Government inspection of radiation shield under operations of abort dump mode and SX mode.

---

1. Acceleration and fast extraction

2. Slow extraction

3. Government inspection

**COD correction**

**Horizontal and Vertical COD Correction**

**Improvement of ripple problem**
Activity of the “RFQ back up group”

- Investigation of the J-PARC RFQ disorder
  - Disassembling and observation of the R&D machine for JHP (432 MHz)
  - Analysis of vacuum, electro-magnetic, multipacting, etc.
- Life extension remedy of the current RFQ
  - Gentle operation and conditioning: prevent damage
  - Should act as soon as possible, improvement of vacuum pressure, etc.
  - We have to use the current machine by the back up one will be ready.
- Study and review of the existing RFQ
  - Current operating and operated RFQ (SNS, ISIS, JHP, JAERI, LEDA)
  - High electric field material, machining, surface treatment, etc.
- Design study and R&D scheme
- Construction of the backup machine

Summary

Current RFQ should be used (alive) at least one and half year.
We should
- operate at a minimum risk,
- have conditioning if needed, handle with care, and
- take action as soon as possible, improvement of vacuum, etc.

Design and construct a backup machine as soon as possible
- Key word: stable operation
- Investigation of disorder and reflection to design work
- Construction
- Standing by after the RF conditioning
- Replacement

RFQ-BUG (back up group)
- Leader: Hasegawa, Yoshioka
- RF-design: Kondo, Morishita, Naito, Yamaguchi
- Vacuum, Structure: Saito, Hori, Matsumoto, Kawamata
- Some specialists