



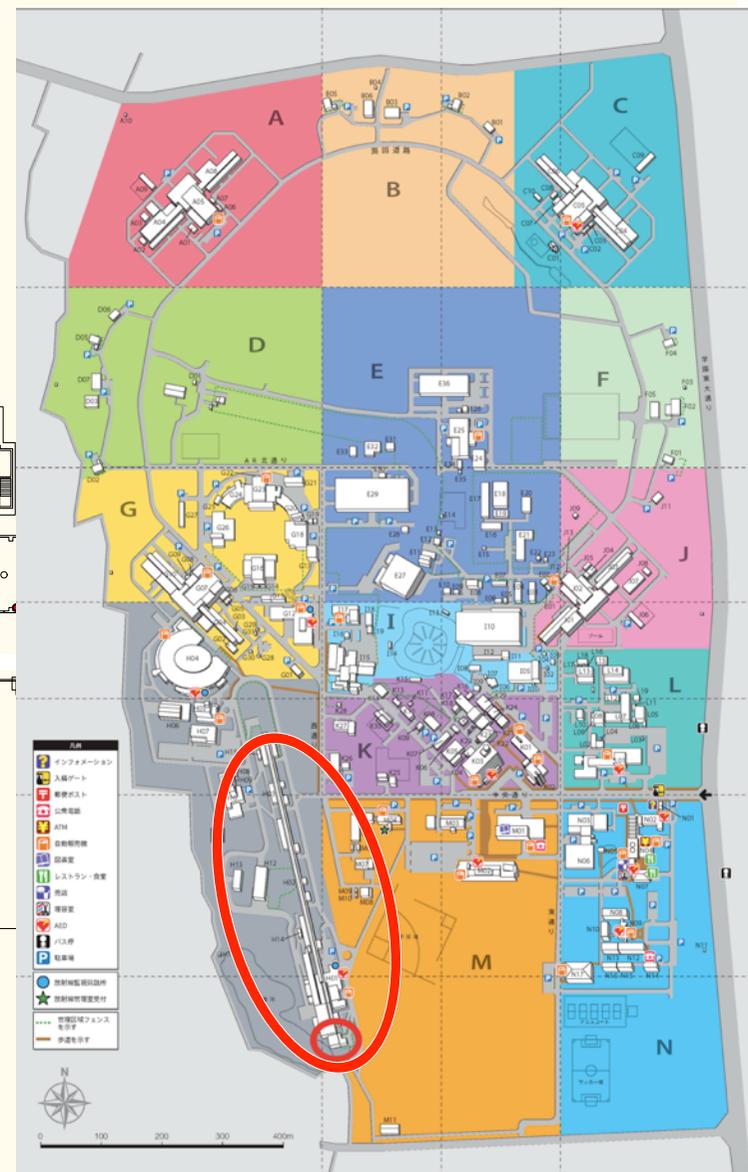
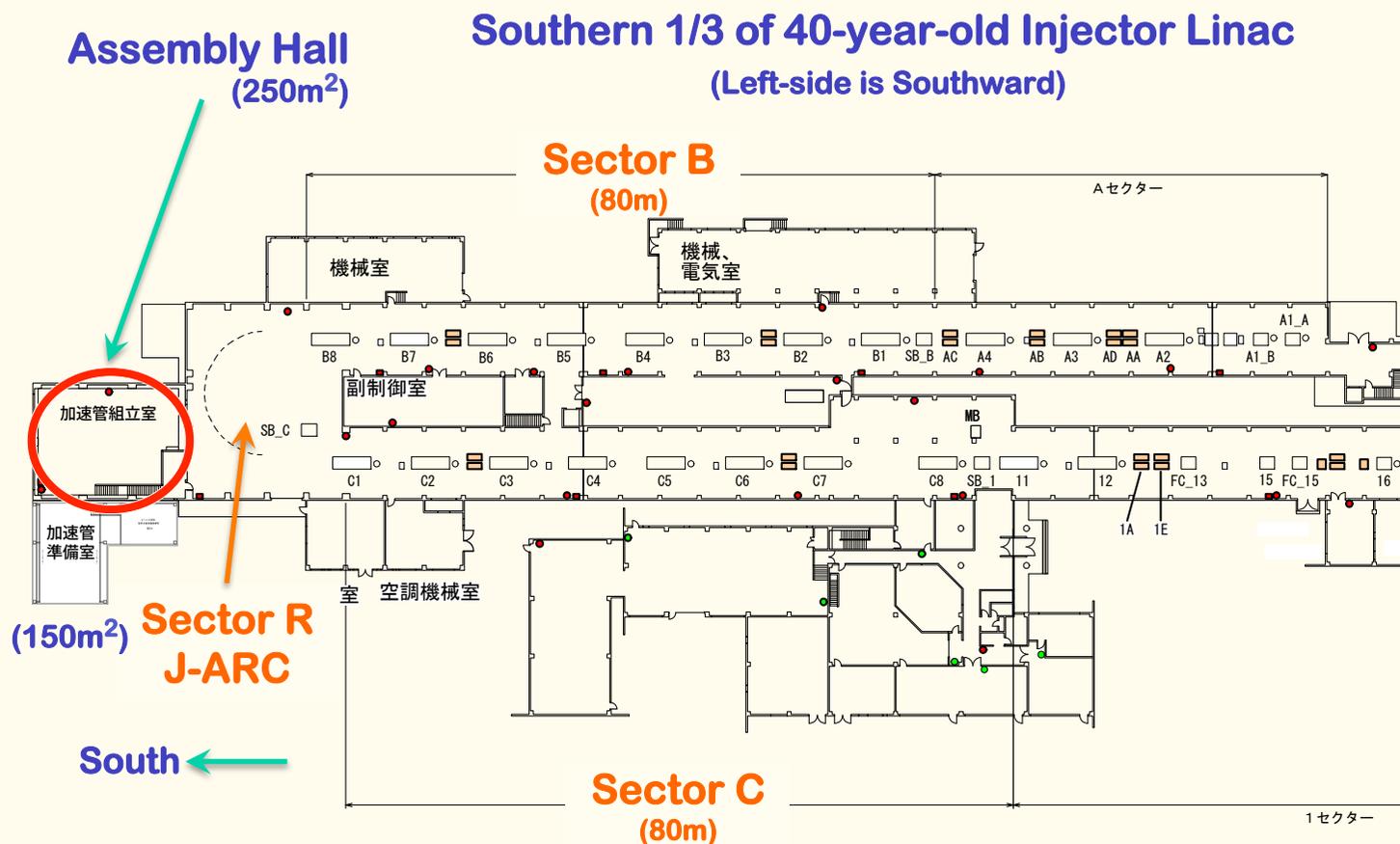
A Fire at KEK LINAC and Its Recovery

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for KEK e^-/e^+ Injector LINAC

Injector Linac Building and Assembly Hall



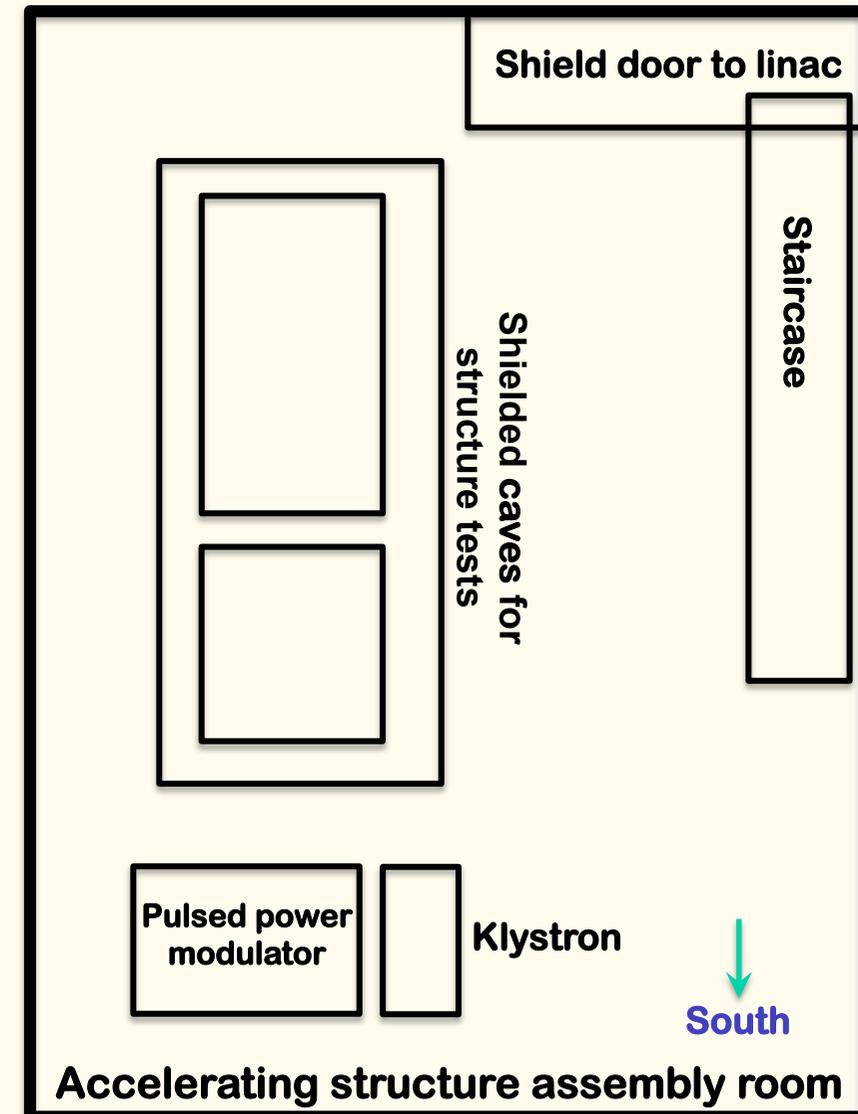
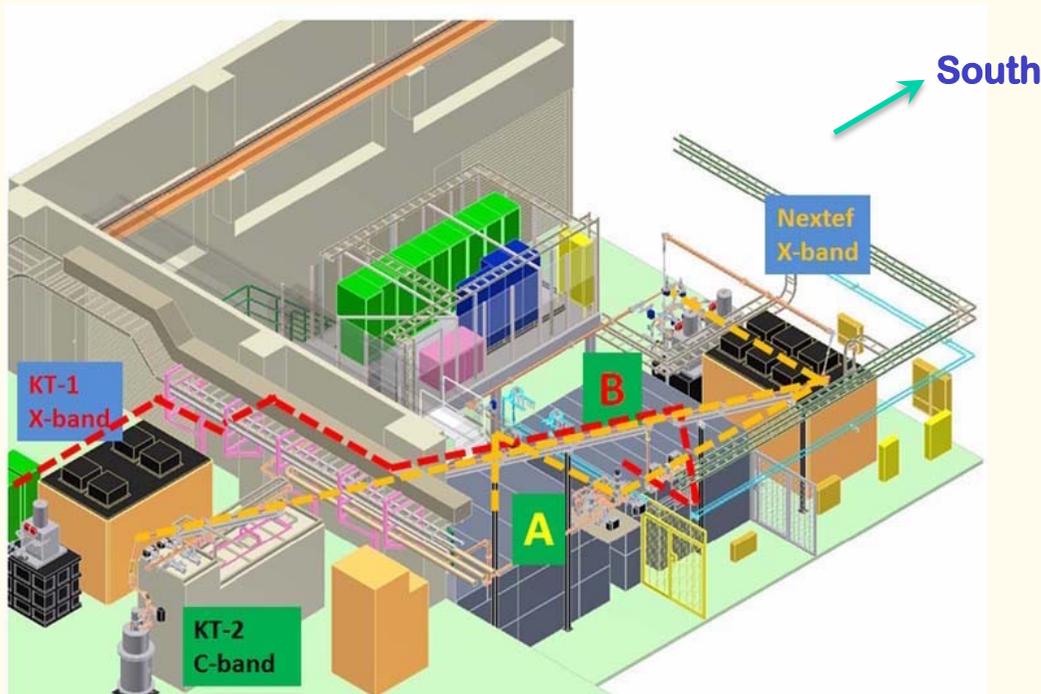
❖ **The fire at the assembly hall affected B,R,C sectors of the injector linac building**

✧ **About 25% of the 700-m injector linac building**

Accelerating Structure Test Facility in the Assembly Hall

◆ Adjacent to the south of the injector building (Apr.2.2019.)

- ❖ X-band, C-band, S-band developments
- ❖ Nextef : research collaboration with CERN and US labs. (for 13 years)
 - ✧ 150 MW high-power pulsed power modulator
- ❖ On the 2nd day of a planned 3-month work
- ❖ Planned to be used for S-band from FY2020



Fire at Injector Linac Building

- ◆ **A fire broke out at the assembly hall adjacent to the injector building**
 - ❖ The hall was used for R&D of S-band, C-band, X-band structures
 - ❖ On the day, a collaboration research program with CERN/SLAC for X-band
- ◆ **A fire started in a microwave high-power modulator**
 - ✧ X-band microwave: 11.424 GHz, 10 - 100 MW, 1 μ s, 50 Hz
 - ❖ An aged capacitor in the pulse-forming network (PFN) burst, discharged, ignited
- ◆ **High-power interlocked, fire-alarm triggered, much smoke**
 - ❖ Fortunately, no injury
 - ❖ Most of equipment was damaged
 - ✧ S-band development at the test-stand was important, and recovered at early 2020
 - ✧ X-band devices were much more damaged, and approved to restart in this month, Sep.2021
- ◆ **Fire stopped when firemen entered (1.5 hour later)**
 - ❖ No media/press investigation (on site)
 - ✧ “No environmental hazards found” on TV and papers
 - ✧ While “no environmental hazards” was surely true, the reality was so disruptive



Finding Overview

- ◆ **No injury (could not enter the hall because of smoke)**
- ◆ **Self-extinguished when firemen entered with oxygen**
- ◆ **No direct fire damage to the main injector linac...**
- ◆ **Large amount of carbon soot sneaked into the injector**
 - ❖ **Discharge might prevent high-voltage operation of high-power pulsed modulators**
 - ❖ **Short-circuit might prevent high-precision operation of the instrumentation**
- ◆ **Chemical material (Dioctyl Phthalate: cancer causing) accompanied with carbon soot**
 - ❖ **Required full Tyvek protective clothing**
 - ✧ **Later, it turned out that the density was rather low, and the clothing was relaxed**
- ◆ **Quick recovery required for SuperKEKB commissioning**
 - ❖ **Large discrepancy in understanding between the institute and the division**
 - ❖ **Investigated technical aspects, resources, and mental health, etc**
 - ✧ **Finally, succeeded in tentative recovery**



Early Difficulties

- ◆ **We entered into buildings just after the extinguishing, however, firemen evacuated us as the level of carbon mono-oxide was high**
- ◆ **The damage in the assembly hall was obvious, however, the impact of carbon soot was significant to the main injector LINAC, that was not recognized by the institute**
 - ❖ **We were told to restart within 3 days**
 - ❖ **However, we estimated that it may take 1-3 months**
- ◆ **Limited material availability**
 - ❖ **Only about 8 sets of protective clothing and masks were available in nearby cities. During the weekend, group leaders started to investigate the damage and to plan the recovery works**
 - ❖ **Later, purchased hundreds of material sets of Tyvek clothing, gas masks with active charcoal, gloves, shoe covers, etc.**



Chemical Hazard

◆ Carbon soot was collected immediately for chemical analysis

- ❖ It takes a month for quantitative analysis normally

◆ Partial analysis on site

- ❖ Only for soluble in organic solvent

- ❖ Diocetyl Phthalate (softener for vinyl chloride)
- ❖ Cancer causing, reproductive toxicity, etc
- ❖ (A month later, found to be safe as the density was too low)



◆ Full protective clothing (Tyvek) (needed also for soot)

- ❖ Detailed explanation was made to contractors as well
- ❖ Youth and women were excluded from the workers
- ❖ Gas masks, Tyvek, goggles, gloves, entrance management
 - ❖ Gas masks were ordered directly to the factory in hundreds
- ❖ Conversation, face-recognition, ...
 - ❖ Names on front/back of Tyvek
- ❖ Air temperature rise
 - ❖ Water and food at the entrance
 - ❖ Daily health suggestions from doctor



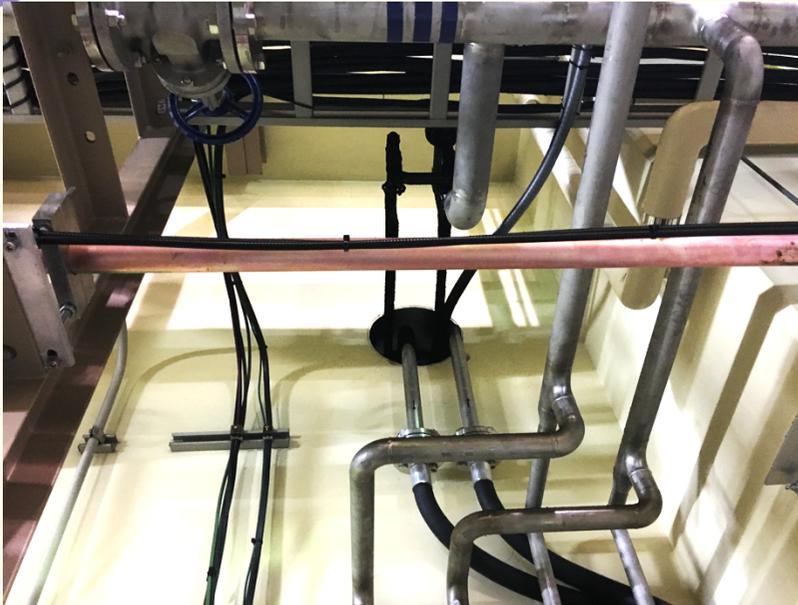


Fireman in the smoke and carbon soot



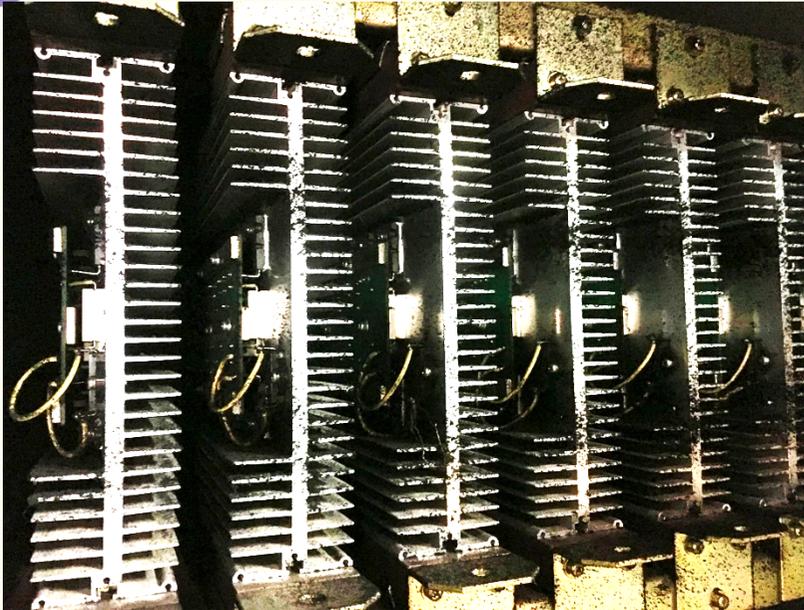
Modulator burnt



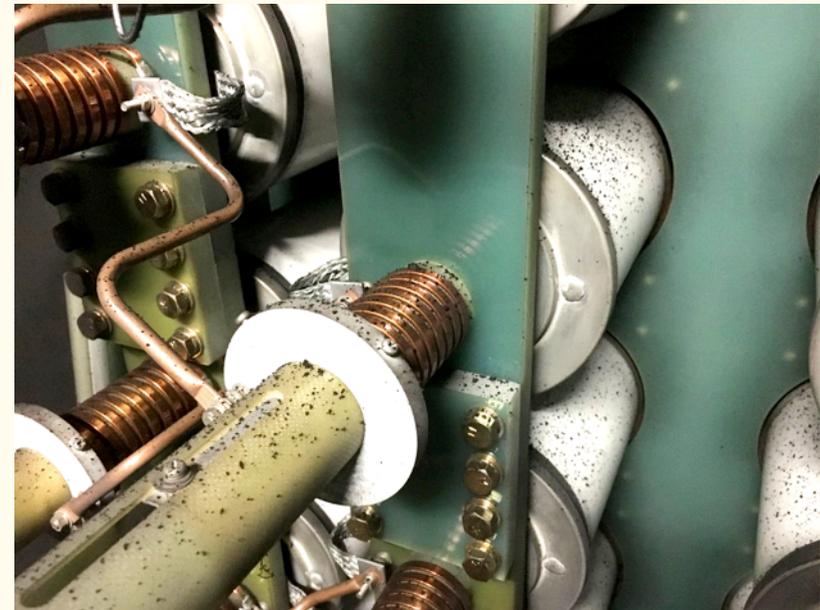


❖ Carbon soot sneaked through holes between rooms





❖ Carbon soot in the equipment





❖ Cleanup one by one



❖ Low-power & high-power tests





◆ Information Sharing via Meeting, Mail and Web

- ❖ Meeting in every morning
 - ✧ Some from other divisions
- ❖ Group leader meeting
in every evening
- ❖ Daily update
- ❖ Mental health
- ❖ Physical health
- ❖ Environmental analysis
- ❖ Recovering strategy
- ❖ Utility recovery
- ❖ Equipment recovery
- ❖ Testing progress
- ❖ Beam schedule

入射器火災復旧について (Linac Fire Recovery, April - November 2019)

[ストレスイベント後の反応について \(安全衛生推進室、大井雄一産業医\)\(Response after stress event, May.10\) \[pdf\]](#)
[電子陽電子入射器の作業者のみなさまへ \(環境安全管理室、安全衛生推進室\)\(Linac safety reminder, Oct.30, NEW\) \[pdf\]](#)
[こころのケアについて \(安全衛生推進室、健康相談室\) \(Mental care, Apr.19\)\[pdf\]](#)
[揮発性有機化合物調査結果と作業管理 \(環境安全管理室、安全衛生推進室\) \(Gas analysis and healthcare, May.27\) \[pdf\]](#) : [word]
[保護具に関する作業管理の質問と回答 \(安全衛生推進室\) \(Gas mask and healthcare Q&A, Apr.22\) \[pdf\]](#)
[保護具に関する作業管理と健康管理 \(安全衛生推進室\) \(Gas mask and healthcare, Apr.19\) \[pdf\]](#)
[入射器棟粉塵濃度測定結果と今後の作業における注意 \(Dust assessment and recovery, Apr.17\) \[pdf\]](#)
[化学物質情報概要 \(Chemical overview, Apr.6\) \[pdf\]](#)
[化学物質情報 \(SDS\) \[pdf\]](#) : [Original link]
[入射器入域安全確保 \(Linac safety, Apr.5, OBSOLETE\) \[pdf\]](#)[安衛室分析 \(Chemical analysis, Apr.5, OBSOLETE\) \[pdf\]](#)
[安全衛生推進室巡視点検報告 \(衛生管理者、安全衛生管理者\) \(Safety health inspection, May.9\) \[pdf\]](#) : [word]
[安全衛生推進室巡視点検報告 \(産業医、産業看護師\) \(Safety health inspection, May.9\)\[pdf\]](#) : [word]
[安全衛生推進室巡視点検報告 \(Safety inspection, Apr.11\) \[mail\]](#) : [word]
[入射器 Beam 立ち上げ進捗 \(Linac restart progress, Apr.25\) \[pdf\]](#) : [excel]
[入射器復旧作業進捗 \(Linac recovery progress, Apr.19\) \[pdf\]](#) : [excel]
[入射器 Beam 立ち上げ進捗概要 \(Linac restart progress overview, Apr.24\) \[pdf\]](#)
[火災報知設備と加速器運転 \(Fire alarm and operation, Apr.19\) \[pdf\]](#)
[施設部復旧情報 \(Utility recovery daily progress, Apr.26\) \[pdf\]](#)
[施設部復旧情報 \(Utility recovery daily progress, Apr.24\) \[pdf\]](#)
[サブ変電室回復情報 \(Substation recovery progress, Apr.16\) \[pdf\]](#)
[対策会議報告と立上げ打合せ \(Recovery daily progress report, Apr.22\) \[mail\]](#) : [powerpoint]
[対策会議報告 \(Recovery daily progress report, Apr.19\) \[mail\]](#) : [powerpoint]
[火災について \(共同利用者の方へ\) \[KEK News\]](#) : [To KEK Users: On the fire, Apr.25 \[English\]](#)
[火災について \(共同利用者の方へ\) \[KEK News\]](#) : [To KEK Users: On the fire, Apr.11 \[English\]](#)
[火災について \[KEK Press release\]](#) : [Fire at linac, Apr.4 \[English\]](#)
[入射器入域手順 \(Linac entrance procedure, Apr.8\) \[pdf\]](#)
[入射器概略図面 \(Linac floor plan\) \[pdf\]](#)
[Gallery 概略図面 \(Gallery floor plan\) \[pdf\]](#) : [Tunnel 概略図面 \(Tunnel floor plan\) \[pdf\]](#) : [空調範囲図面 \(Airconditioner floor plan\) \[pdf\]](#)
[詳細 Mail 共有情報 \(Linac-Update mail archive\)](#)
[入射器復旧写真 \(Linac recovery photo archive\)](#)
[加速器学会報告 \(Report at particle accelerator society, Aug.2\) \[pdf\]](#)
[火災報告 \(Analysis report, Jun.28\) \[pdf\]](#)
[暫定報告 \(Tentative report, May.10\) \[pdf\]](#)
[火災概要 \(Incident overview slide, Apr.8\) \[pdf\]](#)
[火災概要 \(Incident overview slide, Apr.5\) \[pdf\]](#)
[火災概要報告 \(Incident overview 3-page report, Apr.4\) \[pdf\]](#)
[時系列記録 \(Timeline\) \[html\]](#)
[NHK 首都圏 \(Apr.4\)](#) : [つくば市 \(Apr.4\)](#)

Kazuro Furukawa <linac-request@mail-linac.kek.jp>, Apr.7-Oct.30.2019.
[\[Linac \]](#) [\[Linac-update \]](#) [\[SuperKEKB \]](#) [\[Accelerator \]](#) [\[KEK Staff \]](#) [\[KEK \]](#)

<http://www.kek2.kek.jp/sep/2019/>

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Exploration of the Landing Position

- ◆ **Negotiation between early recovery and limitations**
- ◆ **Might take several months to recover all devices**
- ◆ **Abandoned redundancies in certain devices**
- ◆ **Important devices that might need long recovery period**
 - ❖ **Several of 60 high-power microwave modulators**
 - ✧ **Some of them act as redundancies**
 - ❖ **Two magnet power-supplies for 180-degree bending section (J-ARC)**
 - ✧ **One backup existed, fortunately stored in a distant room**
- ◆ **Investigated the beam energy profile around J-ARC**
- ◆ **If it took more than 3 weeks, limited mon-power inside/outside because of consecutive national holidays in May (Golden week)**



Recovery progress

Apr.3: Fire. Carbon soot was anticipated for high-power and high-precision operation.

Apr.4: During the investigation, hazardous chemical material was found as well as carbon soot.

Apr.5, 6: Partial clean-up was performed as a test, and also for devices to be sent out to maker companies, with limited pieces of protective clothing.

Apr.8: As protective clothing arrived, full clean-up started. Several devices were found to be difficult to fix in a short term, and an operation plan was developed.

Apr.18: Low power test started.

Apr.22, 23: High power test was performed successfully.

Apr.23: Beam test began.

Apr.25: Limited SuperKEKB HER injection restarted.

Apr.26: SuperKEKB HER and LER injections, and then the collision restarted.

May.7: PF light source injection started as originally scheduled.



Impact on Injector Recovery

- ◆ **Recovered with much help from everyone**
 - ❖ All divisions in KEK and outside companies joined
- ◆ **Certain equipment recovery was postponed**
 - ❖ Energy lowered from 1.5 GeV to 1.35 GeV
 - ✧ at J-ARC, 180 degree bending section
 - ❖ Until summer shutdown
 - ✧ 2 of 60 RF sources were off
 - ✧ 1 of 2 bending magnet power supplies was off
 - ❖ Found not to impact much on the injection
 - ✧ with the required beam specifications at the time (just after the commissioning)
 - ❖ Mostly recovered before autumn operation
- ◆ **Most of backup devices were consumed**
 - ❖ Many damaged devices were abandoned
 - ❖ Might mean acceleration of renewal for aging devices, actually
 - ❖ Budget depended on insurance refund



Investigations and Countermeasures

- ❖ A review meeting was organized in the accelerator department, and later was endorsed by the institute as well

◆ Fact

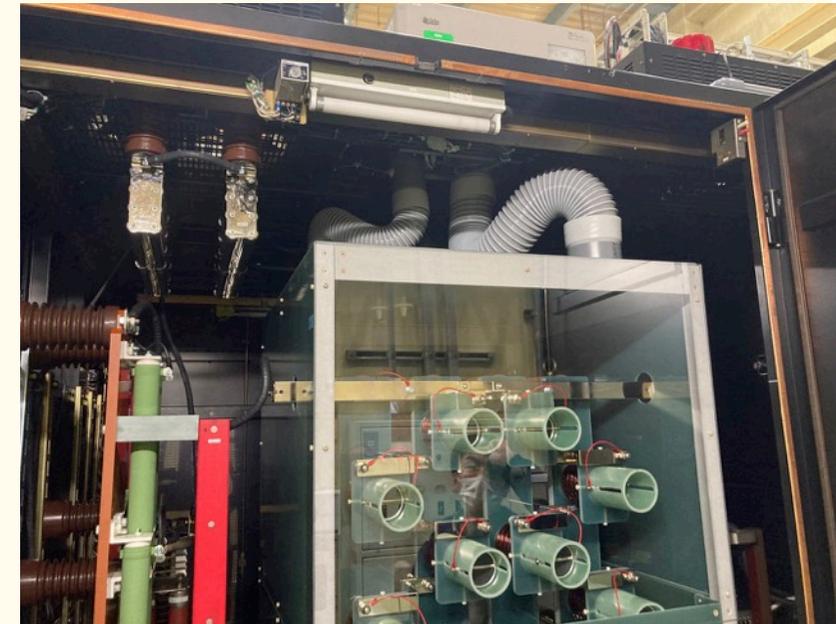
- ❖ A capacitor with plastic container in the pulse forming network of high-power modulator punctured, discharged, and fired
- ❖ The modulator was restarted after the initial interlock without detailed investigations

◆ Recommendations

- ❖ Usage of metal (or ceramic) container capacitors
- ❖ Conservative (long-life) capacitor design with lower gradient
- ❖ Routine inspection of characteristics of capacitors
- ❖ Rigid interlock handling
- ❖ Improve the sensors and video cameras
- ❖ Documentations especially with power board connections
- ❖ Tight communication between main injector operation and test-stand experiments

Auto-extinguisher and Cameras

- ◆ We experienced punctures before
- ◆ We learnt that several other institute experience such fire incidents
 - ❖ At least we got information from SLAC and CERN
- ◆ An automatic extinguisher was installed in the new Nextef modulator
 - ❖ A smoke sensor triggers non-combustible gas into PFN box
- ◆ Hundred of video cameras were installed to observe interlocked devices in main LINAC





Operation Considerations

◆ Capacitors at injector are different from Nextef's

- ❖ Has ceramic container instead of plastic container
- ❖ Has lower designed potential gradient (longer lifetime)
- ❖ Has puncture protection
- ❖ Performed degradation check every other summer (tangent delta)



◆ Tentative operation procedure in injector linac

- ❖ Local operator investigation is enforced on modulator HV interlock
 - ✧ Observation for any anomalous behavior or capacitor puncture
- ❖ More frequent observation of southern part of injector

◆ More surveillance devices would be installed

◆ Important to start S-band structure assembly in 2020

- ❖ As originally planned to fight against aging structures
- ❖ Structure assembly room should be recovered early

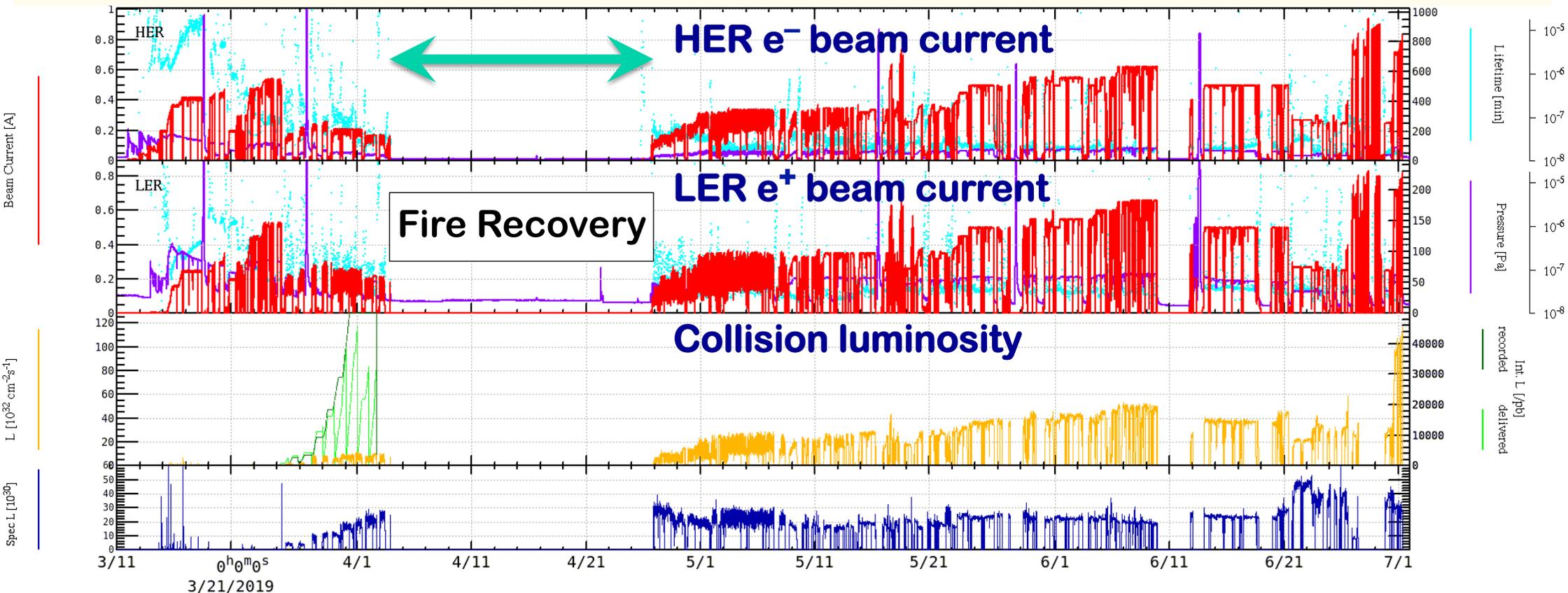


◆ Careful knowledge transfer from the original designer to the next generation

Impact on SuperKEKB Operation

◆ Beam suspension for 3 weeks

- ✧ at the first stage of phase 3 operation
- ✧ at the middle of luminosity development



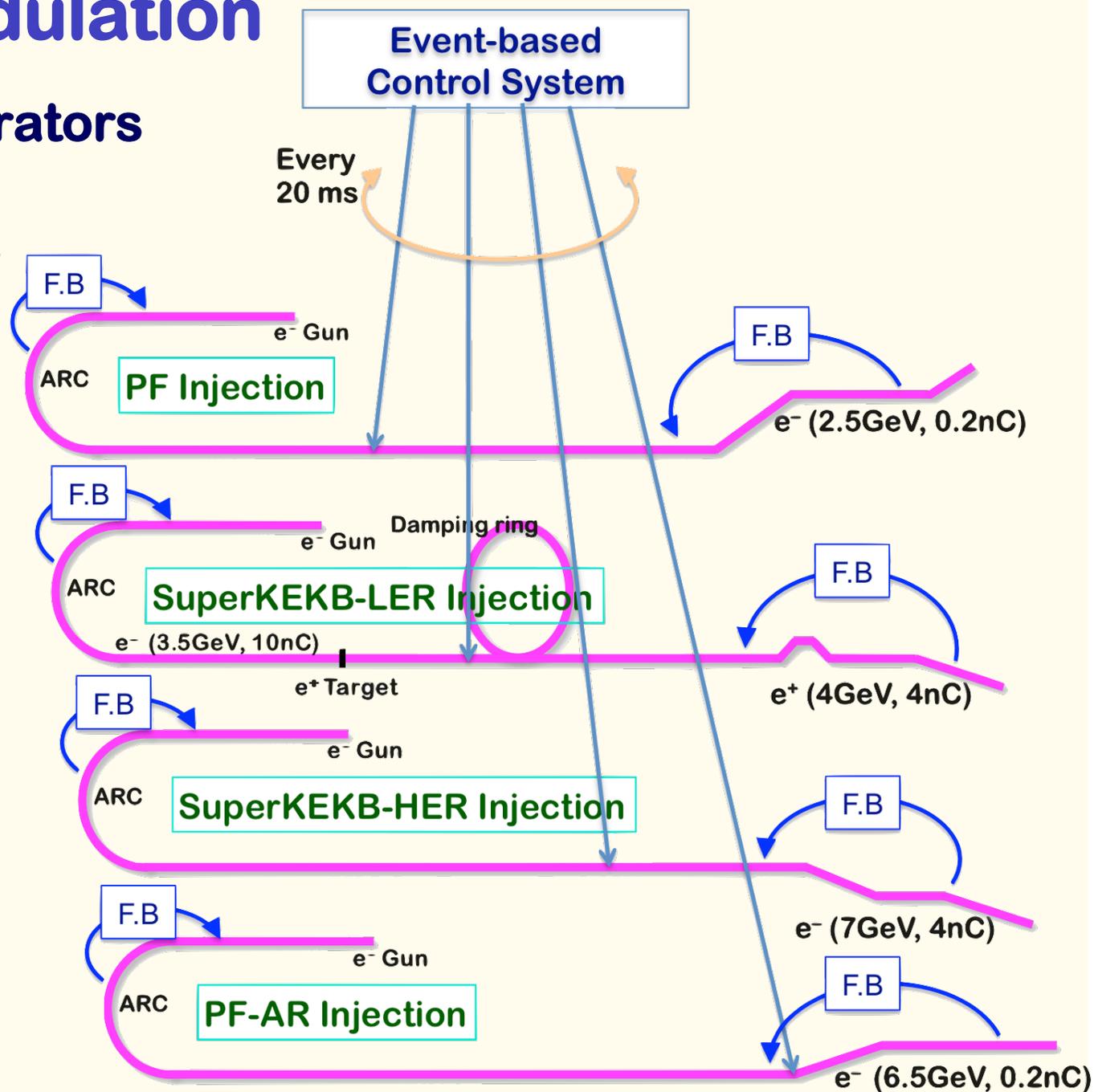
Pulse-to-pulse modulation

- ◆ Four PPM virtual accelerators for SuperKEKB and photon science projects

- ◆ As initially planned in May.2019

Based on
Dual-tier controls with
EPICS and event-system

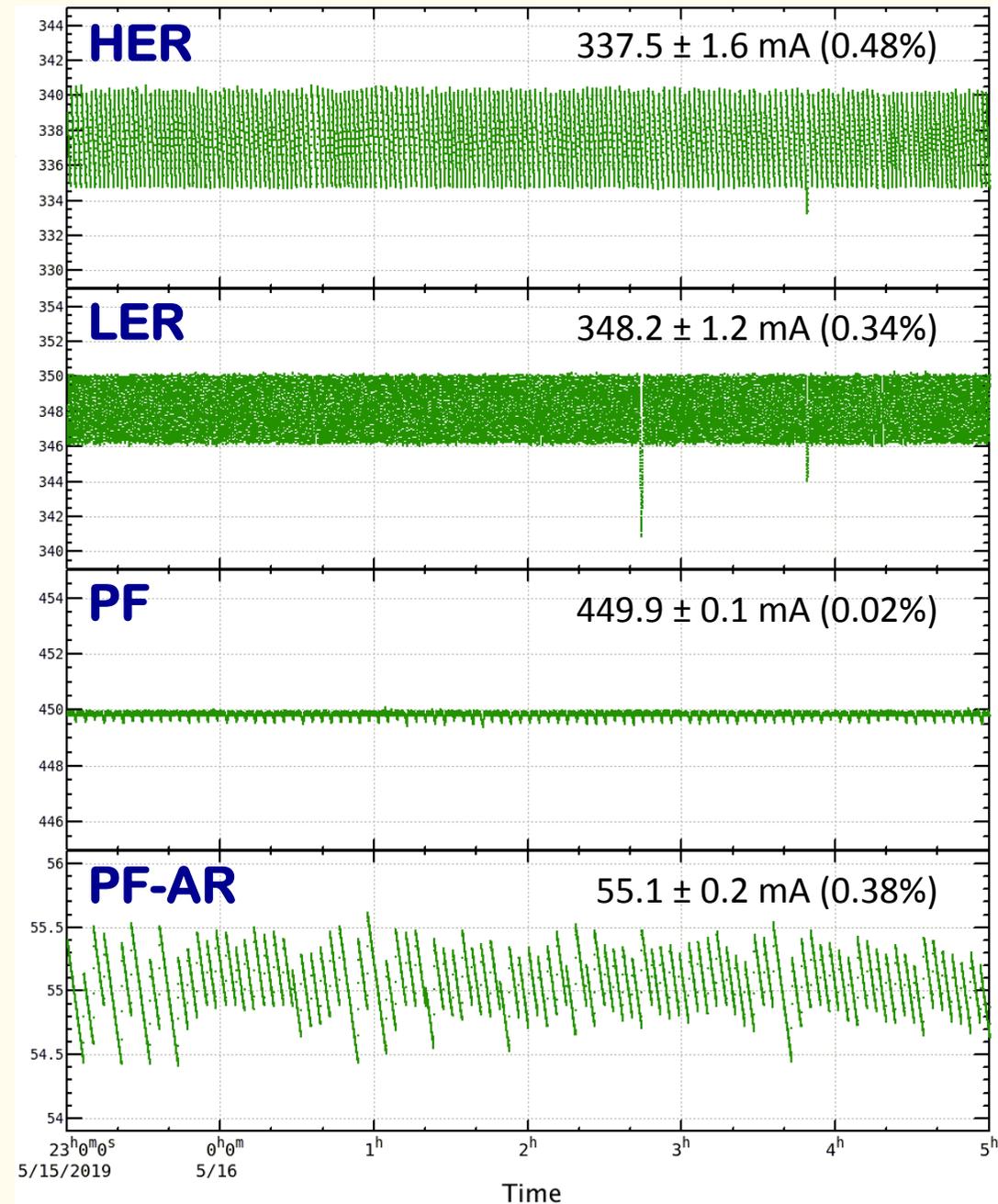
Independent parameter sets
for each VA (20ms)



Simultaneous 4 + 1 Ring Top-up Injection

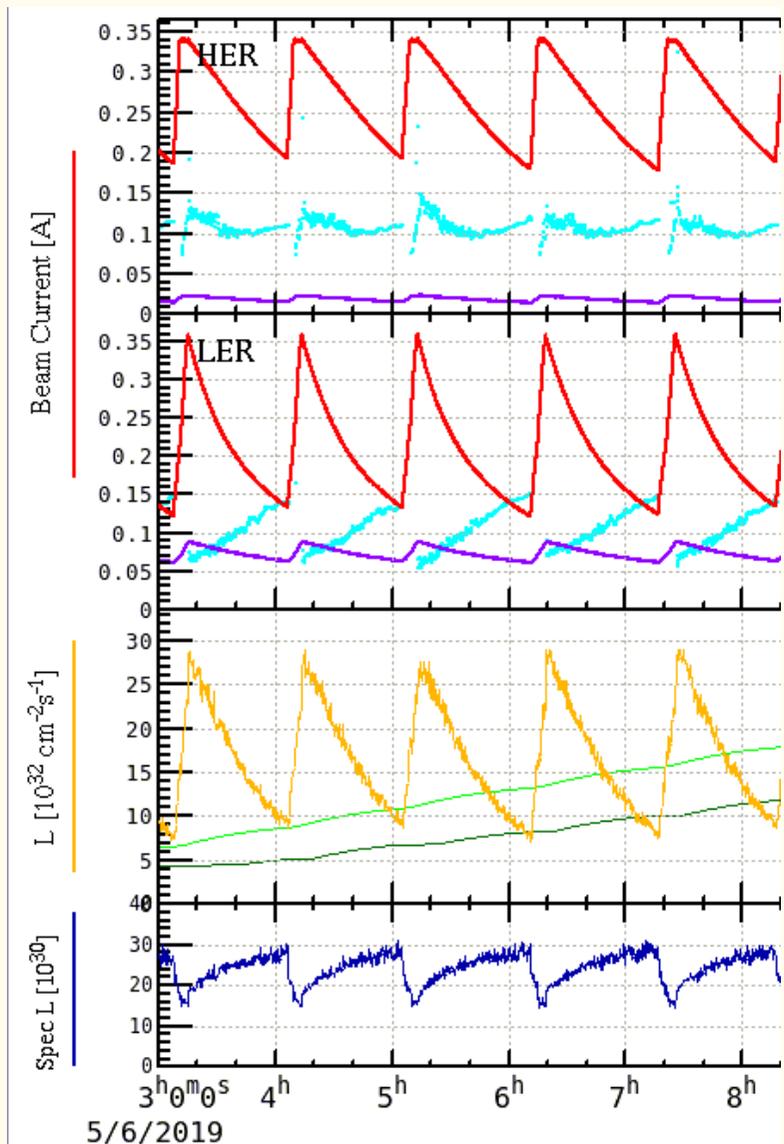
◆ Realized for the first time

- ✧ SuperKEKB HER 7 GeV e⁻
 - ✧ SuperKEKB DR and LER 4 GeV e⁺
 - ✧ Photon Factory 2.5 GeV e⁻
 - ✧ PF-AR 5.0 / 6.5 GeV e⁻
- ❖ 4 beams are modulated at 20 ms PPM
 - ❖ More than 200 pulsed devices were constructed for SuperKEKB, as well as beam and RF monitors
 - ❖ Injection noise (background) were well studied from the 2nd week of May



Simultaneous Top-up Injections

◆ Integrated luminosity improvement (example)



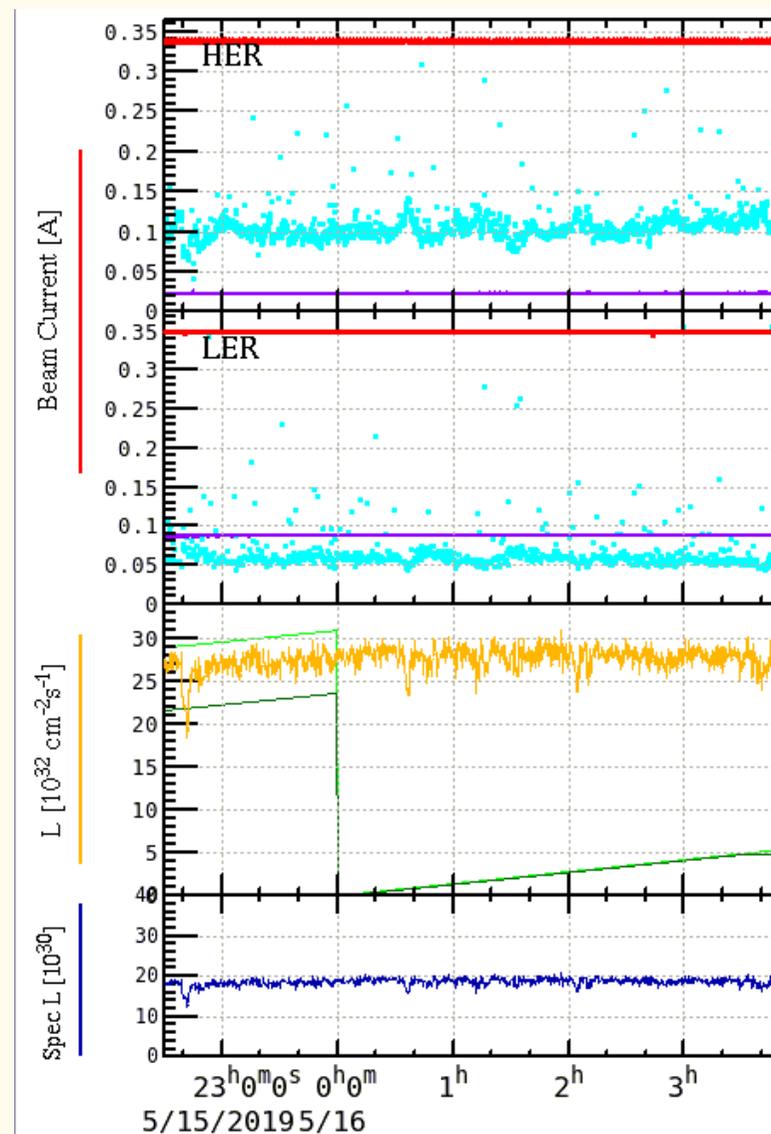
**17.54 /pb in 5.15 hr
(5 fills)
on May.6**



**41.64 /pb in 5.15 hr
(top-up)
on May.16**

**237%
improvement**

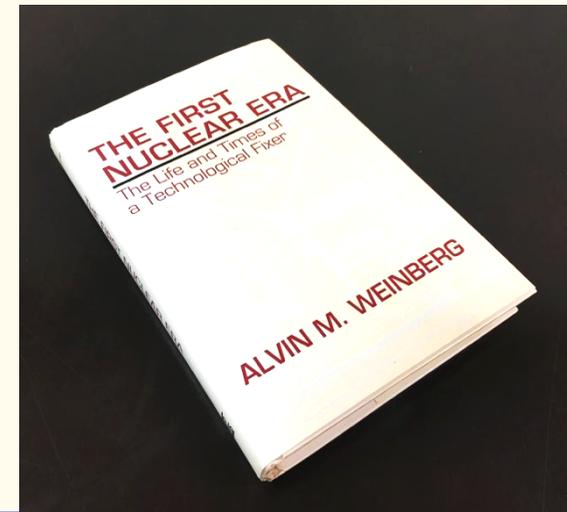
**Heavy work in April
was rewarded**





Trans-science

- ◆ I was much astonished to see such a big disaster in our facility
- ◆ That reminded a word “Trans-science” by Alvin Weinberg
 - ❖ He invented the light-water reactor in Navy for submarine, but insisted that it is too dangerous for civilian applications. Later, he as the director general of ORNL invented Thorium molten-salt reactor. But the world didn't appreciate him until recently.
 - ❖ If the probability of an incident is very low, we make mistakes in the evaluation, and tend to or try to forget that.
- ◆ We need to keep balance between many conditions with pursuing scientific evaluations.

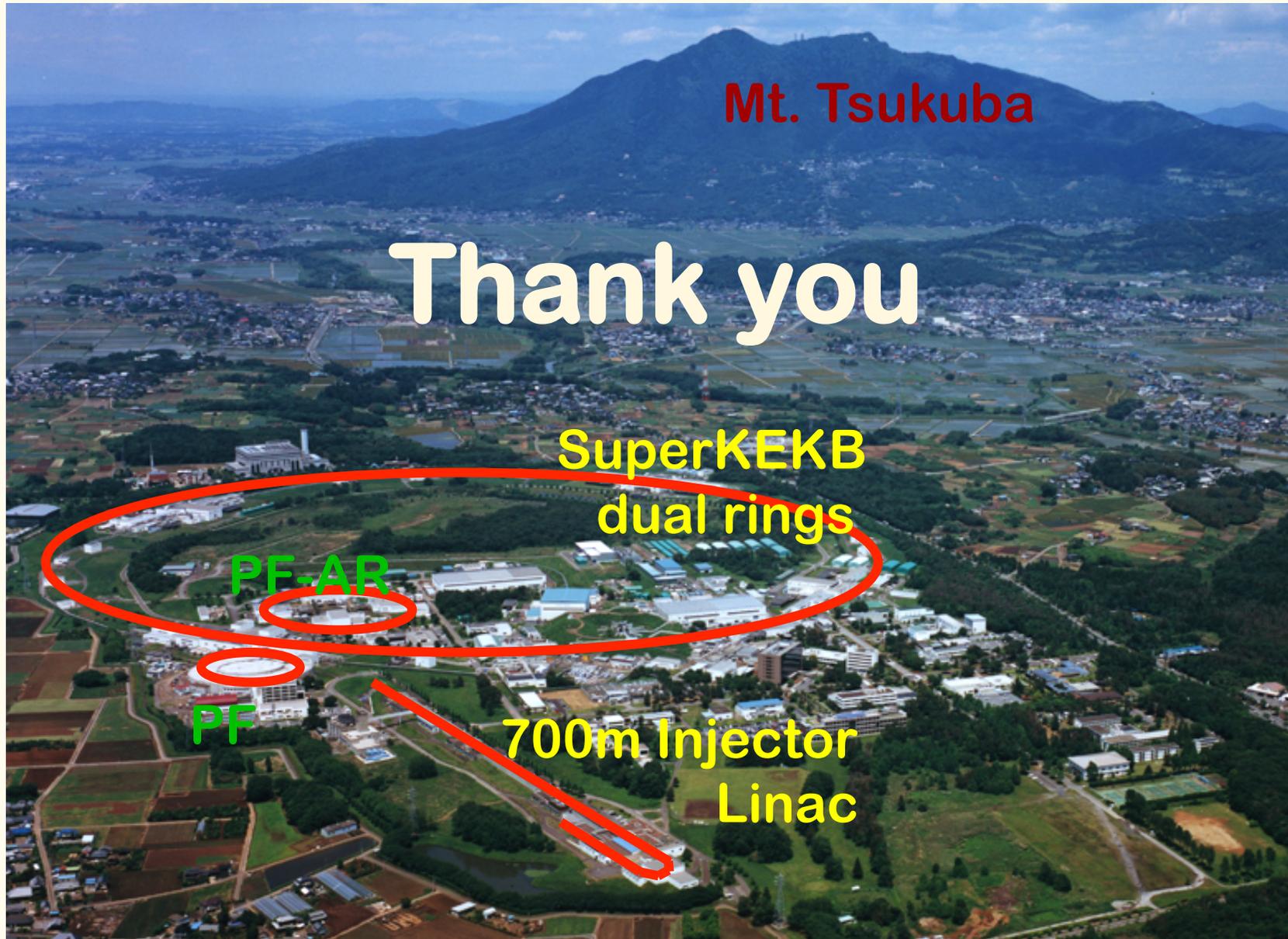




Summary

- ◆ **We should not have the same disaster, with better preparation**
- ◆ **We could have learnt from other institutes**
- ◆ **We could be very nervous in unusual situation, be prepared**
- ◆ **We've mostly recovered from the disaster**
- ◆ **Active safety measures are necessary instead of reacting only**
- ◆ **We are improving with the experiences**

- ◆ **With some Phronesis we can enjoy accelerators**
 - ❖ **Phronesis [Greek]: Practical wisdom, Ability to understand the Universal Truth**



Conference papers at <http://www-linac.kek.jp/linac/>

