Comparison of beam trip frequencies between estimation from current experimental data of accelerators and requirement from ADS transient analyses

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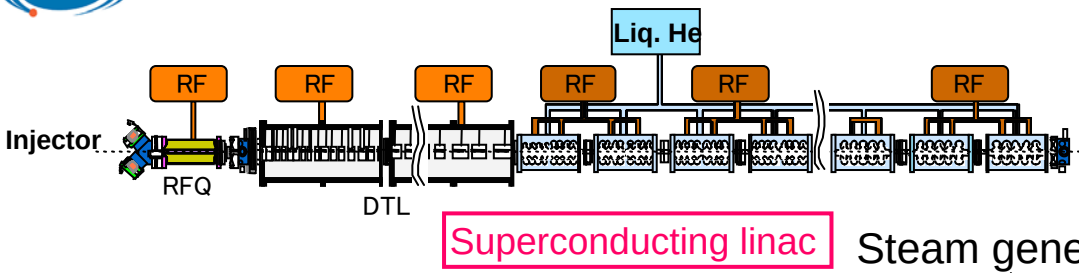
1. Introduction

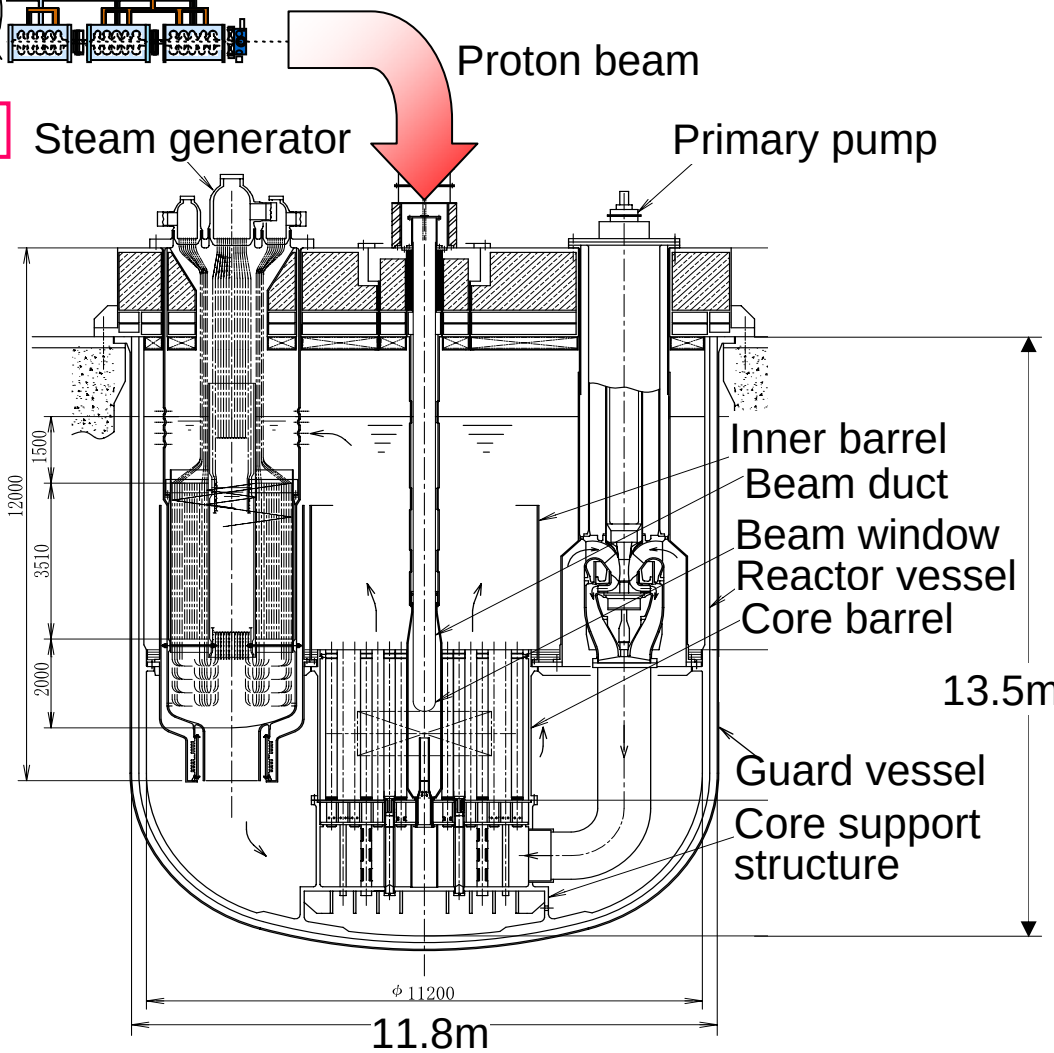
- Frequent beam trips may cause thermal fatigue problems in ADS components which may lead to degradation of their structural integrity and reduction of their lifetime.
- Beam trips are caused by two reasons:
  - Failure of the accelerator components
    ➡The reliability parameters of accelerator components are usually used.
  - Interruption by a Machine Protection System (MPS)
- **Influence** for the thermal shock damage on **the ADS reactor system** caused by beam trips has **not** been **evaluated sufficiently**.
- Conversely, it is **not yet clear** how often the ADS reactor system can accept for the beam trips.

- The purpose of the present study is to know the present level of accelerator technology by comparing beam trip frequencies estimated from operation data of existing accelerators and the requirement from transient analyses of the ADS reactor system.

2. Conceptual Design : Reference ADS



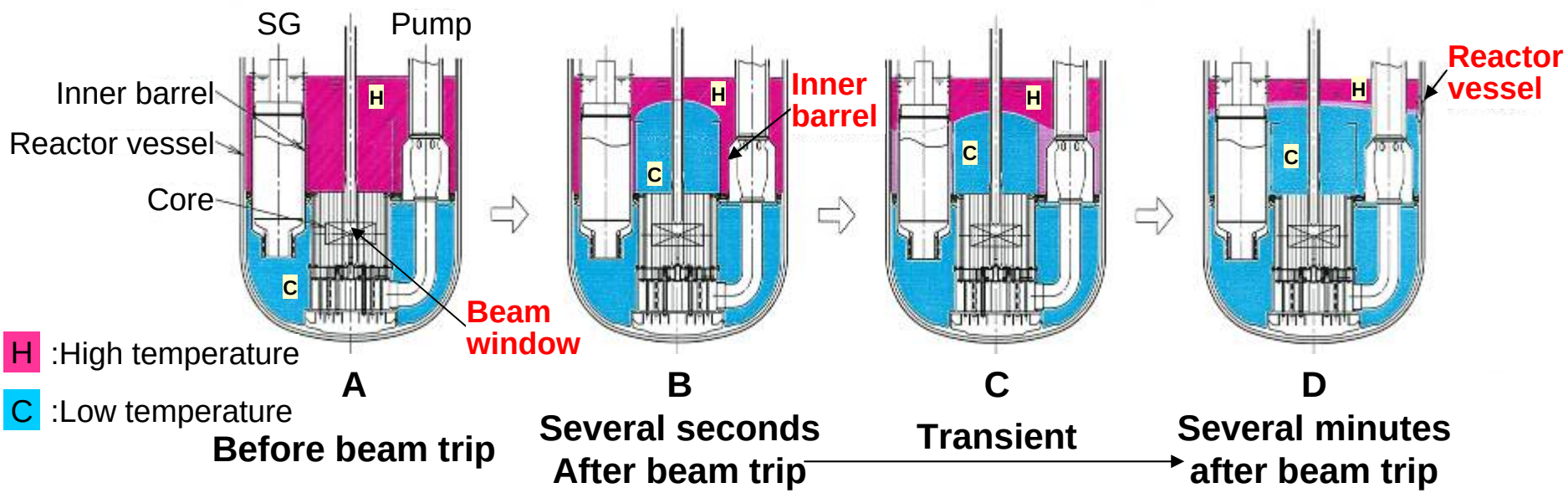
- Beam energy : 1.5 GeV
- Max. beam current : 20 mA
- Klystron : 972 MHz, 750 kW (cw)
- # of klystrons : 89
- Spallation target : Pb-Bi
- Coolant : Pb-Bi
- Max. k_{eff} = 0.97
- Thermal output : 800 MWt
- MA initial inventory : 2.5t
- Transmutation rate :
  10%MA / Year
- 600EFPD, 1 batch



3. Acceptable Frequency of Beam Trips

- **Thermal stress caused by beam trip** is estimated to know acceptable frequency of beam trip.
  1. **Beam window**
  2. **Inner barrel**
  3. **Reactor vessel**

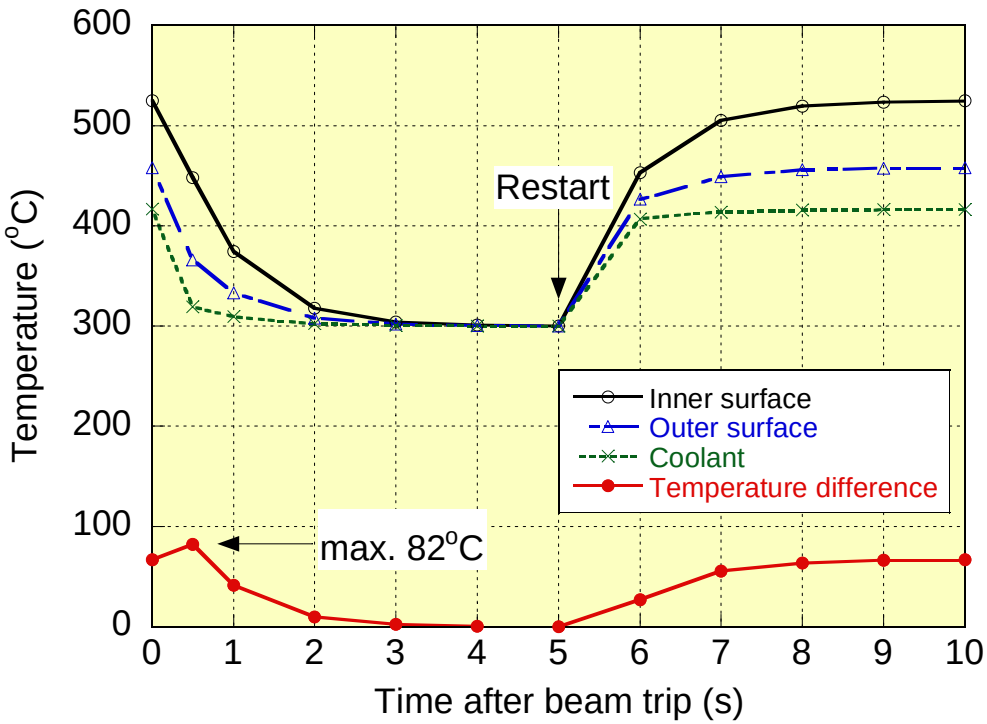
- The influence of the beam trip to the **power generation system** is also estimated.



Acceptable Frequency of Beam Trips :

Thermal Shock on Beam Window

- Beam window :
  450mm$^{\phi}$, 2mm^{t}, 9Cr-1Mo steel,
  beam power: 30 MW
- Beam trip will cause max. **179 MPa** thermal stress 0.5 sec. after the beam trip.
- This thermal stress is much lower than a criteria to prevent buckling failure.
- The acceptable number of this thermal shock : about **10^5**
- Several beam trips per an hour is acceptable for 2 years (about 15,000 hours)
- It should be noted that this estimation is based on the material data without radiation damage.

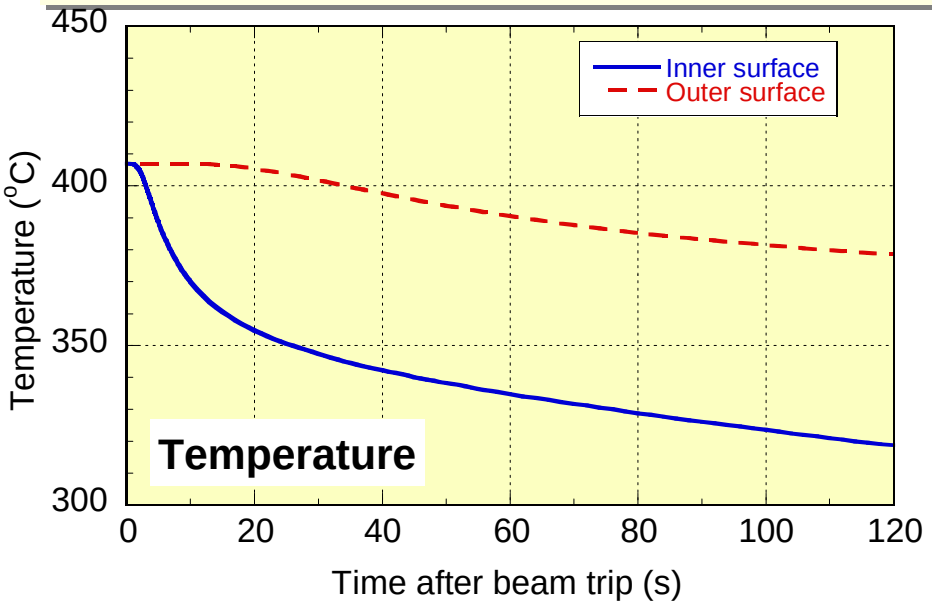


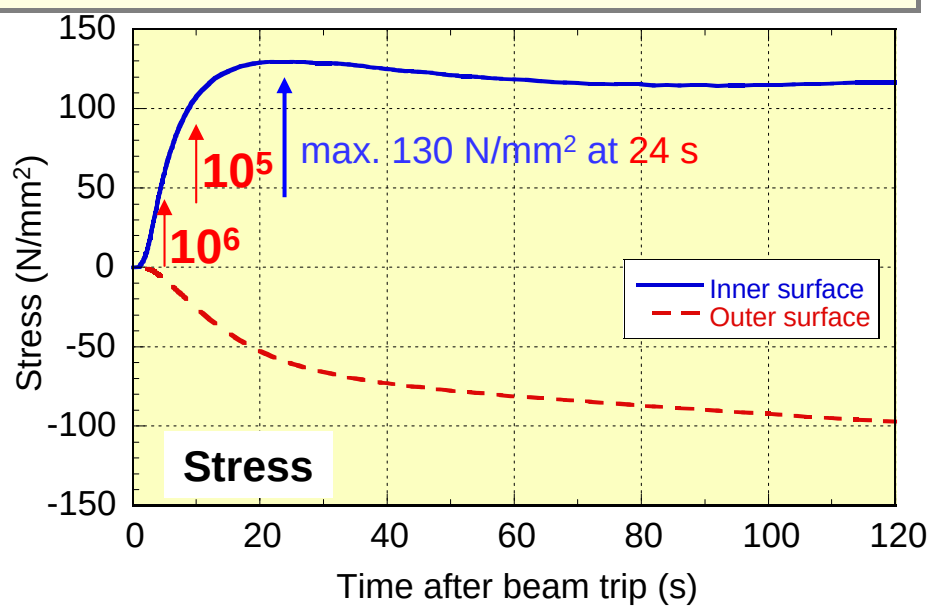
Temperature of beam window at beam trip transient

Acceptable Frequency of Beam Trips :

Thermal Shock on Inner Barrel

- Inner barrel : 3cm^{t}, 9Cr-1Mo steel
- Beam trip will cause max. **130 MPa** thermal stress **24** sec. after the beam trip.
- The stress range will be **260 MPa** considering the following restart transient.
- The acceptable number of this thermal shock : about **10^4**
- 250 trips per year is acceptable for 40 years.
- The acceptable number increases, provided that the beam is reinjected into the subcritical core within about ten seconds after the beam trip.



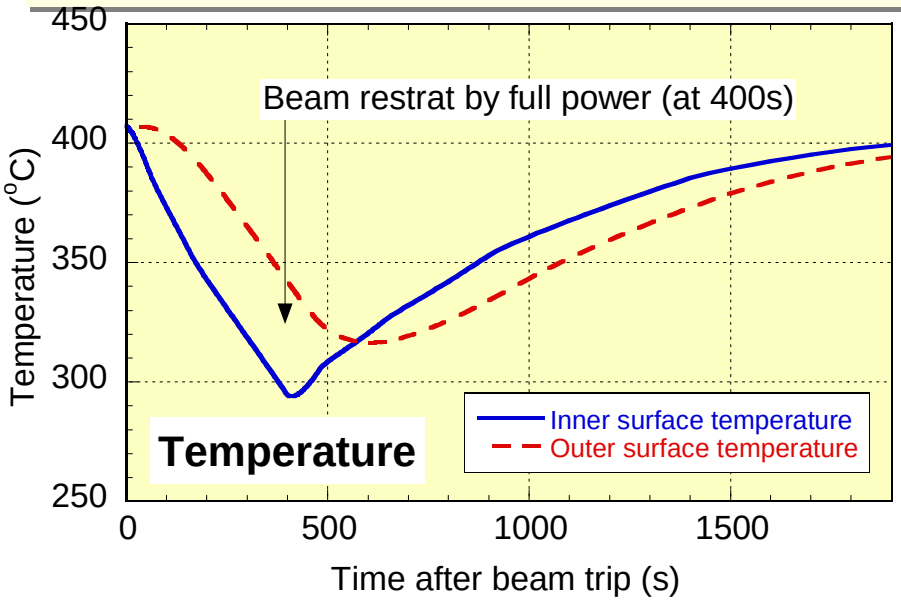


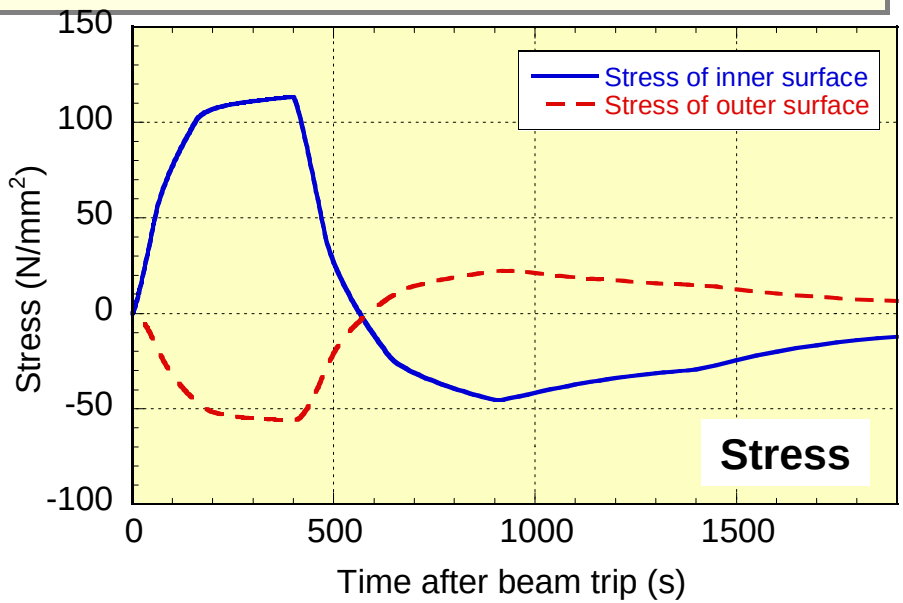
Temperature and stress of inner barrel at beam trip transient

Acceptable Frequency of Beam Trips :

Thermal Shock on Reactor Vessel

- Reactor vessel : 5cm^t, 9Cr-1Mo steel
- Temperature difference between inner and outer surface will cause **113 MPa** thermal stress just before beam restart (400 s).
- Additionally, the formation of the temperature stratification and the LBE level lowering by thermal shrinkage will also cause **109 MPa**.
- In total, the stress range will be **270 MPa** considering the following restart
- The acceptable number of this thermal shock : about **10^4**
- 250 trips per year is acceptable for 40 years.



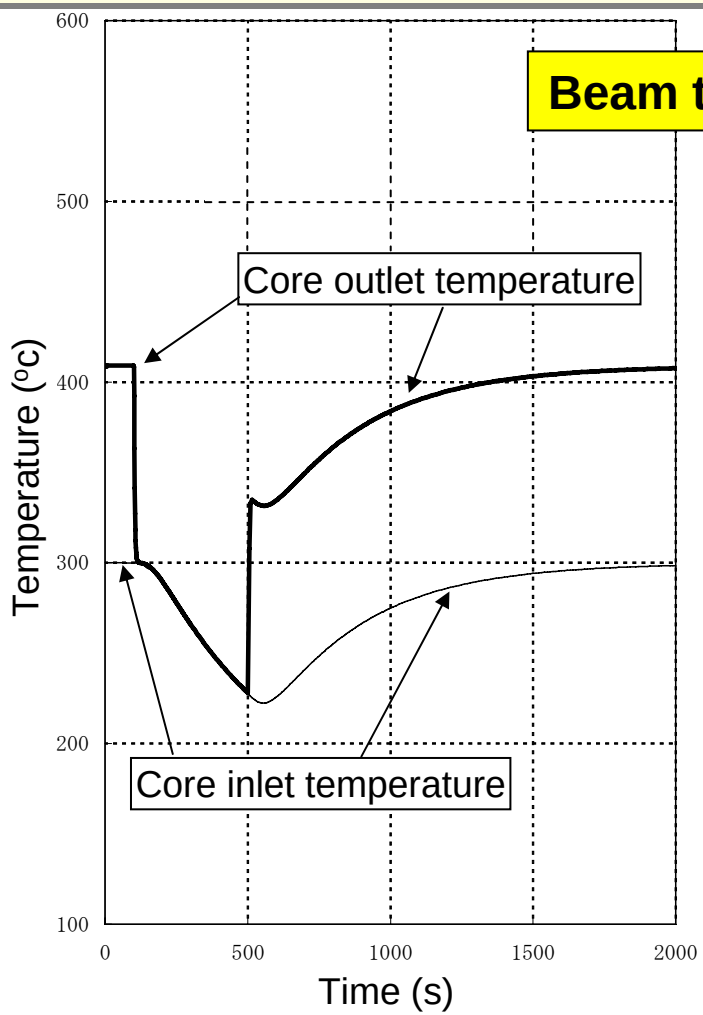


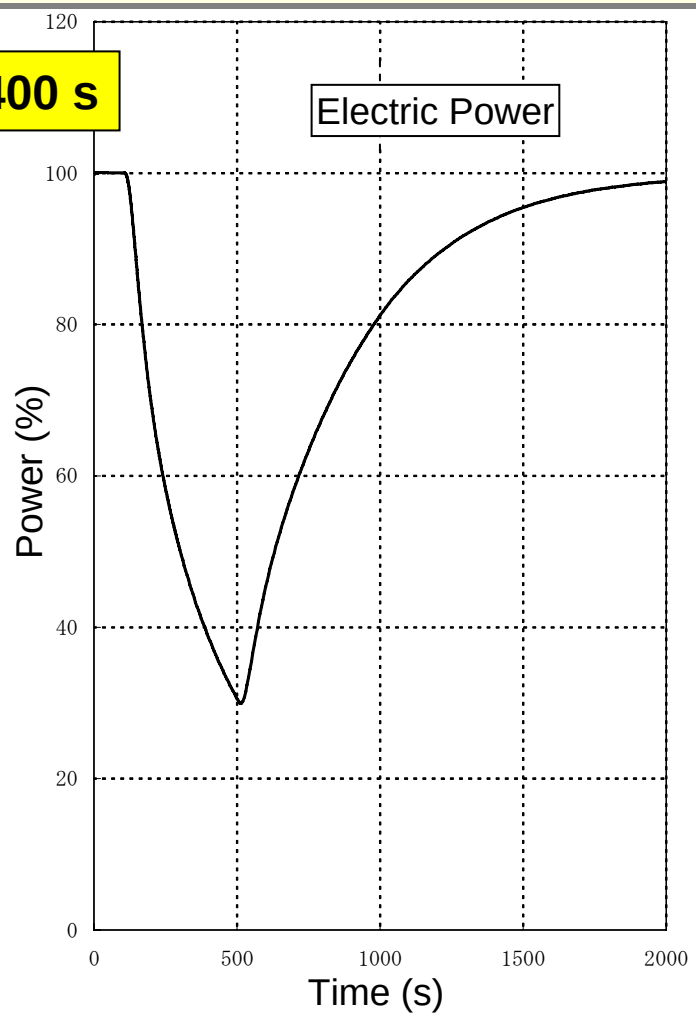
Temperature and stress of reactor vessel at beam trip transient

Acceptable Frequency of Beam Trips :

Behavior of Electric Power Generation System

- Saturated steam cycle with steam drums enables us to continue power generation in case of short beam trip.





Summary

- Four criteria depending on the beam trip duration *T*

Beam trip duration *T*	Acceptable Frequency	Remarks
0 < *T* < 5 sec.	10^5 / 2 year 10^6 / 40 year (25,000 / y)	Beam window life time Fatigue failure of reactor structure
5 < *T* < 10 sec.	10^5 / 40 year (2,500 / y)	Fatigue failure of reactor structure
10 sec. < *T* < 5 min.	10^4 / 40 year (250 /y)	Fatigue failure of reactor structure
T > 5 min.	Once a week (50 /y)	System availability

4. Estimation of the Beam Trip Frequency Based on the current experimental data

- Beam trip frequency of the JAEA's SC-linac was roughly estimated as:

  $N_{ads} \sim N_{inj} + N_{rf}$

  Because **85 %** of beam trips were caused by the **injector** and the **RF system** of LANSCE.

Injector	Scheduled beam time	Beam Trip Frequency
LANSCE (1997) *p*	2,870 (*h/year*)	**1.3** (*times/h*)
SILHI (1999) *p*	104	**0.01**

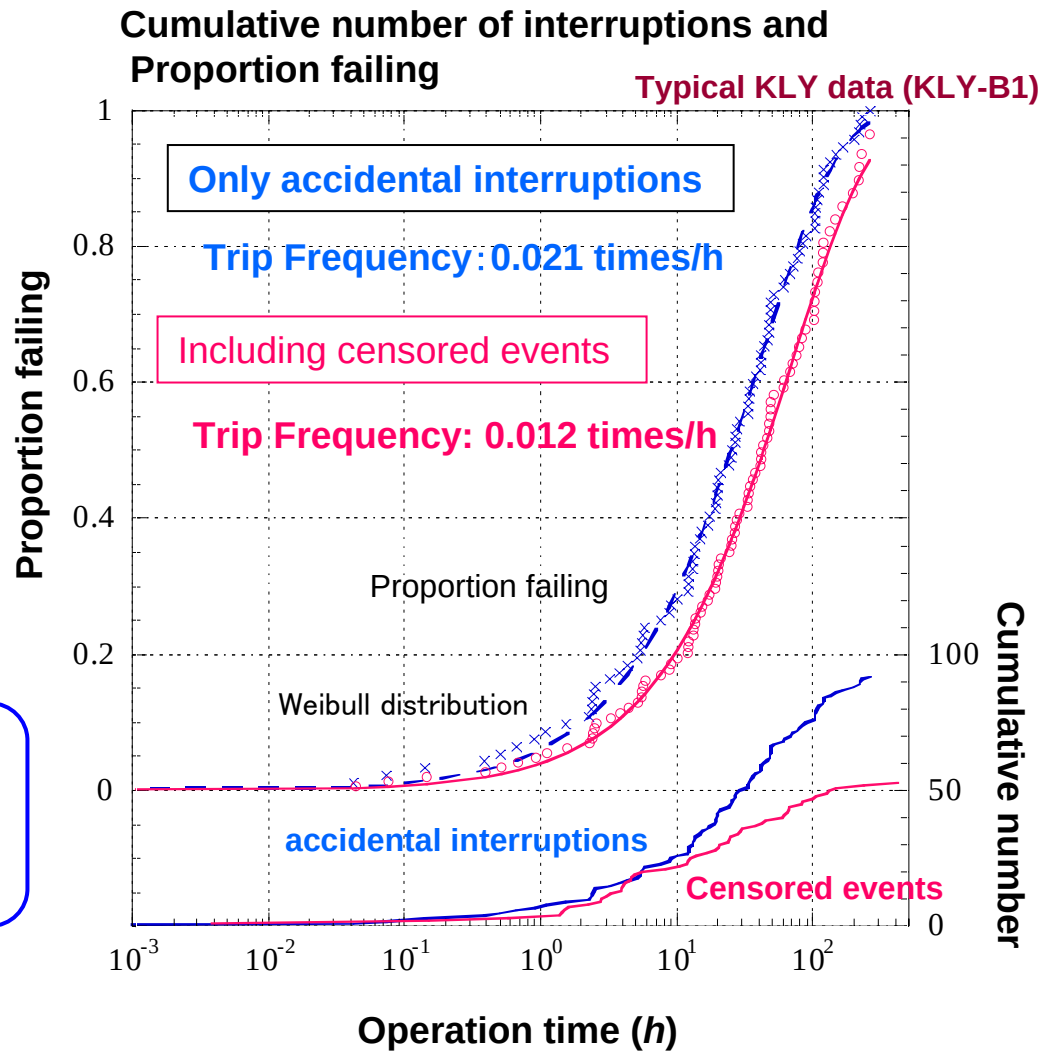
RF system	Scheduled beam time	Beam Trip Frequency	# of KLYs
LANSCE (1997) *p*	2,870 (*h/year*)	**0.001** (*times/h/KLY*)	44
KEKB linac (2005) e^+/e^-	6,815	**0.03**	60
ADS *p*	7,300		89

- Necessity of KEKB linac data:
  - # of KLYs and beam time per year are closer to the ADS linac.
  - Detail data analysis including censored events can be performed.

Estimation of the Beam Trip Frequency :

Censored events in the KEK data

- **Censored events**
  - Manual termination for regular maintenance operations
  - Deactivating request from other systems
- # of censored events in KEK data: **18 %** of all beam trips



Weibull distribution

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right]$$

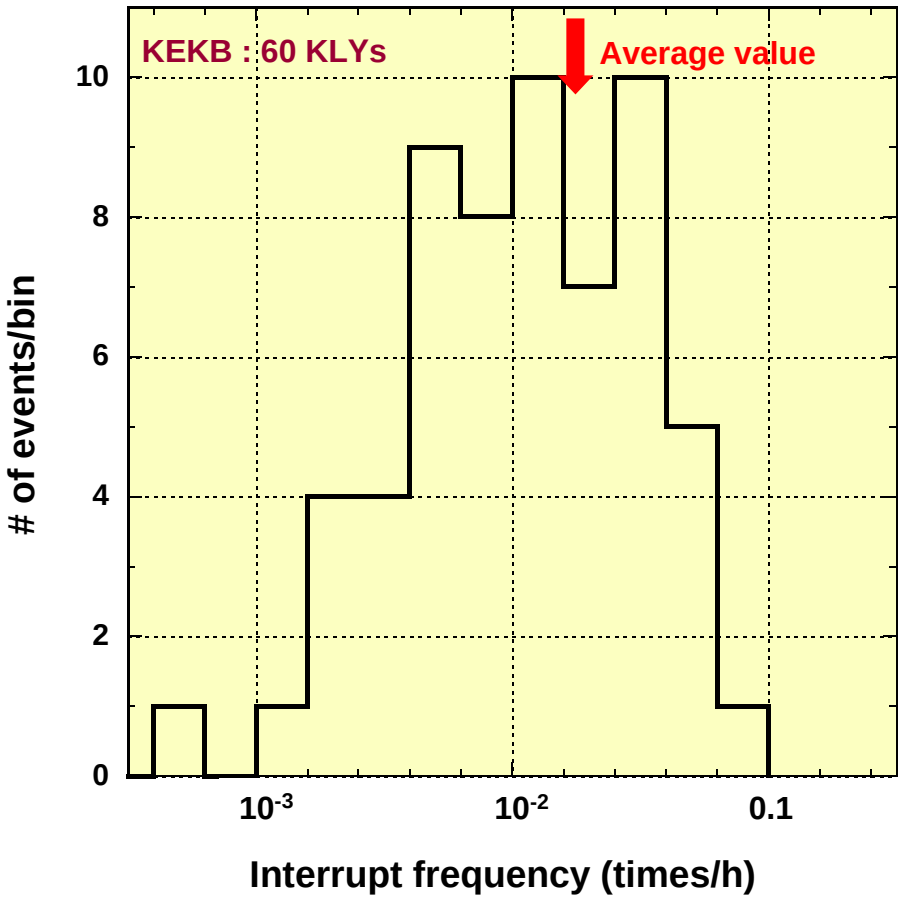
Trip frequency: λ

$$\frac{1}{\lambda} = \alpha\Gamma\left(1 + \frac{1}{\beta}\right)$$

Estimation of the Beam Trip Frequency :

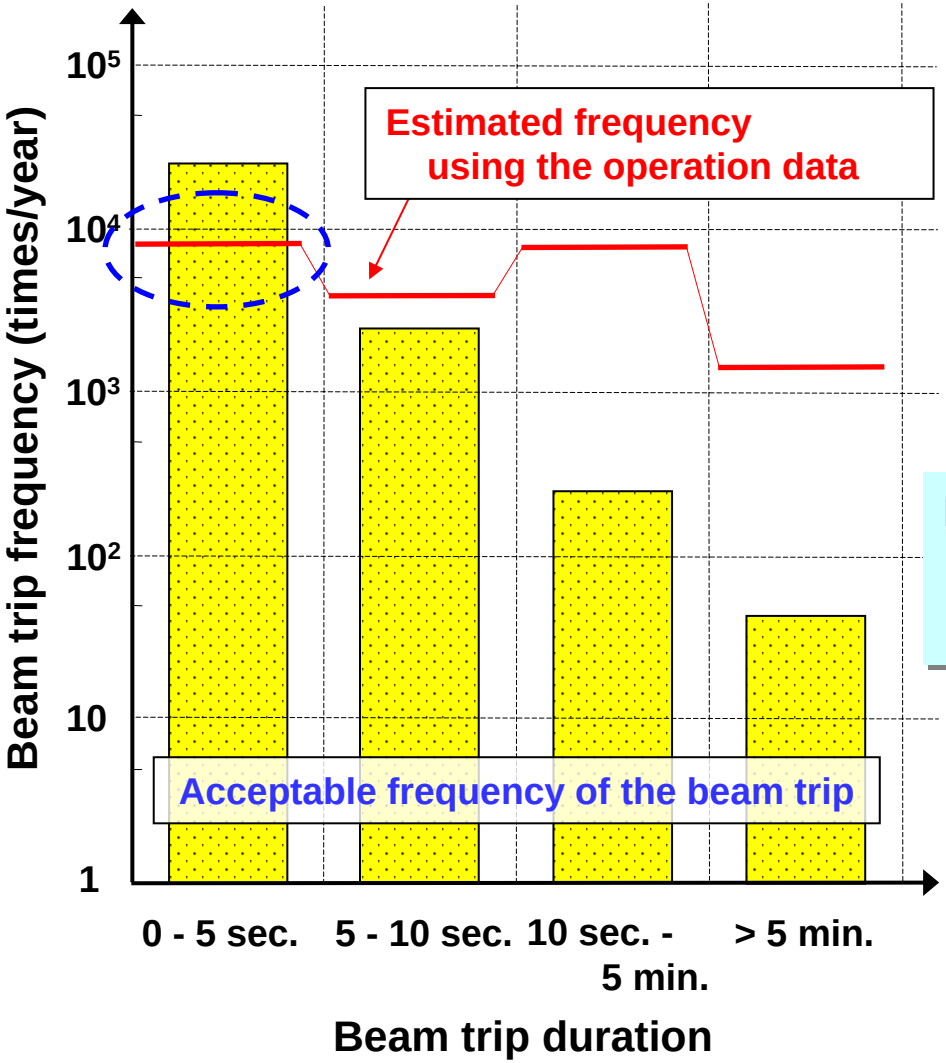
Interrupt frequency of the klystron

Distribution of the interrupt frequency for each KLY



- Accidental interrupt frequency ranges from **$6.1*10^{-4}$** to **$7.9*10^{-2}$** times/h.
- **Average** frequency is estimated as **$1.7*10^{-2}$** times/h.
- N_{rf} ~ **9,900** times/year

5. Comparison of beam trip frequencies



- N_{inj} ~ **9,100** times/year (LANSCE)
- N_{rf} ~ **9,900** times/year (KEKB linac)

- The beam trip frequency (***T* < 5 sec.**) is within the **acceptable value** at the **present level** of accelerator technology.

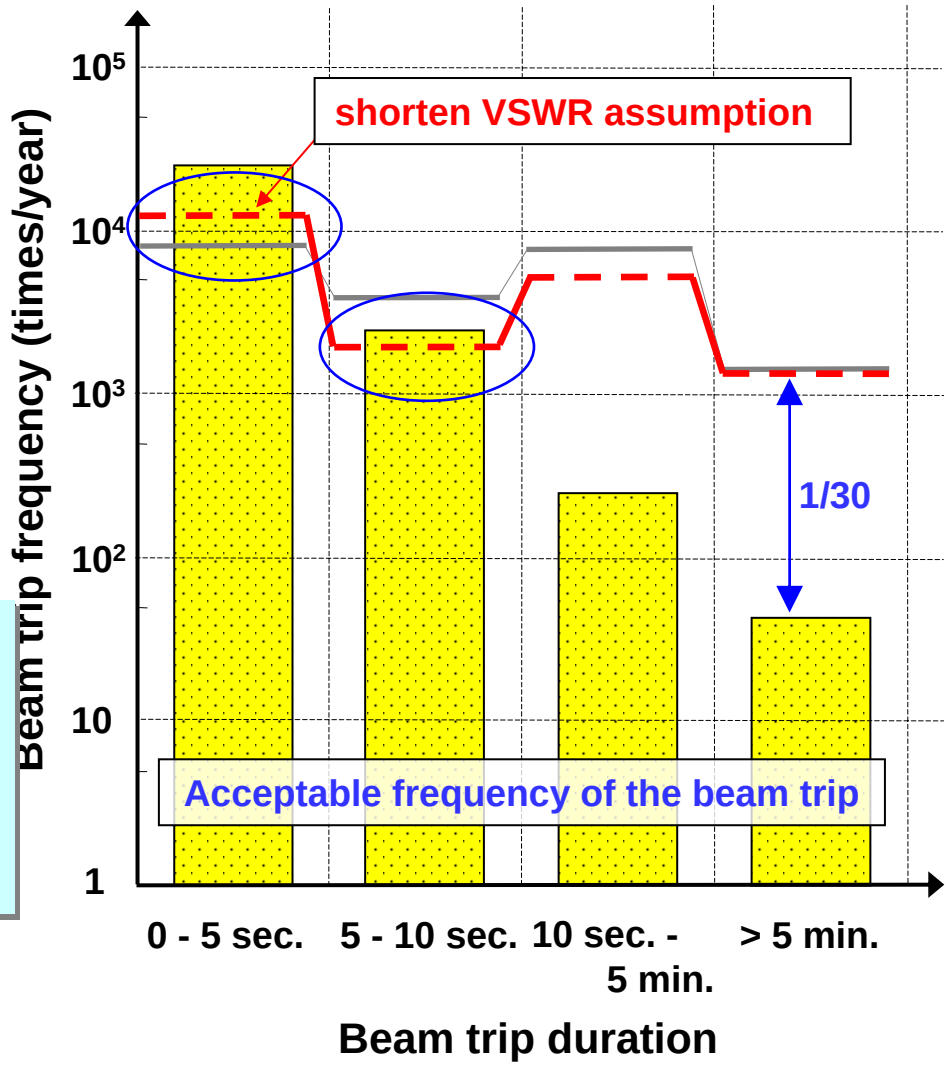
Comparison:

Strategy to Reduce Beam Trip Frequency

- **78 %** of all accidental interruptions were **VSWR** events.
  To protect the RF window
- The bulk of the down time for VSWR events is less than **5 sec**.

Shorten VSWR assumption :
Reduction of the duration of all VSWR events down to 5 sec.

- The beam trip frequency (***T* <10 sec.**) is within the acceptable level.
- While that **exceeding 10 sec.** should be reduced by about **1/30** to satisfy the thermal stress conditions.



6. Concluding Remarks

- In order to measure the effect of reducing beam trips on the high power accelerator for ADS, it is important to **know the present level of accelerator technology**.
- The **acceptable frequency** of beam trips ranges from **50** to **$2.5*10^4$** times per year, depending on the beam trip **duration, *T***.
- It is also necessary to include **censored events** in the analysis of the accelerator components related to the beam trip frequency.
- The beam trip frequency (***T* < 5 sec.***) is within the **acceptable** value at the present level of accelerator technology.
- Under the **shorten VSWR assumption**, the beam trip frequency **(*T*<10 sec.)** is within the acceptable level, while that **exceeding 10 seconds** should be **reduced** by about **1/30** to satisfy the thermal stress conditions.

In the future

- Study the hardware methods for reducing VSWR events to five seconds or less.
- Analysis of the frequency of beam trips with consideration of the frequency with which broken components are exchanged.
- Accumulation of operating data of J-PARC etc.