Derivation of Values to Calculate CSI in Revised IAEA Regulations

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Credits

International group of experts

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Calculations carried out by:

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Aims

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- To replace existing fissile exceptions (especially 15g per package & 5g in 10 litres)
- Provide simple scheme
- No Competent Authority approval required
- Claim credit for low enrichments

What is CSI ?

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Criticality Safety Index controls accumulations of packages.

- Assigned to a package
- Between zero and 50
- Maximum total CSI of 50 usually permitted on a vehicle

How is CSI Calculated ?

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Calculated by identifying maximum safe numbers of packages under normal & accident conditions (N_1 and N_2)

- Normal conditions $5N_1$ safe
- Accident conditions $2N_2$ safe
- CSI = $50 / \min(N_1 , N_2)$

CSI – Variable or Constant ?

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- Usually calculated assuming maximum permitted contents leading to a single CSI for the design
- Partially filled package will have same CSI - usually
- CSI based on actual contents – no reason why not

Example – UF6 Heels

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Normal Conditions

- package remains intact
- Unlimited number of packages safe (N_1 infinite)

Accident Conditions

- package fails + contents released
- contents of all N_2 packages must be safe.
- CSI calculated to ensure a total CSI of 50 has ½ a safe mass

General Design

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- Concept generalised for use with any package
- Minimal knowledge of package design required
- Must provide equivalent safety to approved fissile package design

Accident Conditions

- Packages fail.
- Safety guaranteed by limiting contents of all packages to a safe mass.
- Stage one – agree on safe mass

Considerations

- Spherical Metal systems with FWR
- Higher fraction critical for very low enrichments
- Heterogeneous systems for low enriched uranium
- CH2 moderation

Safe Masses

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Consensus safe U235/Pu masses were agreed:

	H2O	CH2
U(1.5%)	4000	2900
U(5%)	1100	770
U(10%)	900	610
U(20%)	790	530
U(100%)	600	420
Pu	400	260

Calculation of CSI

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$$CSI = 2 \times 50 \times \frac{\text{mass of U235 or Pu in package}}{\text{Safe Mass}}$$

Will limit mass in a total CSI of 50 to ½ a safe mass

Meets the “2N” Accident requirement

Normal Conditions

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- Equivalent safety to approved fissile package design
- “5N” normal conditions array must also be safe
- Can’t show safety on mass alone
- Must claim for package

Normal Conditions

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- Claim spacing by packages but nothing else
- Need minimum package size (30cm)

  Why 30cm ? >10cm but <50cm
- Maximum package contents (CSI<10)

  Why 10 ? consistency with old 15g exception

Package Mass Limits

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- CSI=10 will be achieved by

	H2O	CH2
U(1.5%)	400	290
U(5%)	110	77
U(10%)	90	61
U(20%)	79	53
U(100%)	60	42
Pu	40	26

Most Reactive Shipment

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- 5 packages each with CSI=10
- Must show 5 x 5 = 25 packages safe

Calculations

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- Very large numbers of calculations
- 3x3x3 array of 30cm cubic packages
- Optimum Moderation
- Geometry optimised (offset 1/8 spheres etc)
- Variety of filling materials (SiO_2)

Maximum safe mass per “package” calculated

Results

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- Package masses were greater than those for accident conditions except for U(1.5%)
- U(>5%) normal conditions are bounded by accident conditions
- U(1.5%) is bounded by the normal conditions
- Use normal condition mass limits for U(1.5%)

Revised Safe Masses

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	H2O	CH2
U(1.5%)	2900	2000
U(5%)	1100	770
U(10%)	900	610
U(20%)	790	530
U(100%)	600	420
Pu	400	260

Problems with 2 Columns

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- Scheme assumes mixing of contents of all packages on vehicle
- May not be able to guarantee no CH2
- Acceptable trace quantity of CH2
- Mixing of packages with CH2 and those without
- Water from external source must be considered
- CH2 from external source (oil tanker)

Solutions

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- Use CH2 values only – too pessimistic x
- Use H2O values only – unacceptable to many x
- Compromise – midway value ✓

Final values midway between two

Final Table 13

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U(1.5%)	2200
U(5%)	850
U(10%)	660
U(20%)	580
U(100%)	450
Pu	280

Other Packages

- Could have packages that fail normal condition tests (or are <30cm)
- CSI calculated to ensure total fissile mass when CSI=50 is 1/5 of a safe mass
- $CSI = 5 \times 50 \times \frac{\text{mass of U235 or Pu in package}}{\text{Safe Mass}}$
- CSI<10 retained for consistency
- Limited practical use

Final Package Limits

	Package survives normal conditions test	Package doesn't survive normal conditions test
U(1.5%)	220	88
U(5%)	85	34
U(10%)	66	26
U(20%)	58	23
U(100%)	45	18
Pu	28	11

Pros

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- Easy to use (need only know fissile mass)
- Gives large package and vehicle mass limits for low enrichments
- Accumulations properly controlled by CSI
- Individual package limit is higher than existing 15g fissile exception

Cons

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- Packages previously shipped as fissile excepted will now be fissile
- Fissile mass per vehicle is more restrictive than existing exception for higher enrichments

Further Work

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All CSIs are equal and a vehicle could carry any combination up a total of 50

- Packages with different enrichments
- Mixture of different formulae
- Natural Uranium

Could safety ever be compromised ?