Material Selection of Permanent Magnets, Considering Thermal Properties Correctly

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Spontaneous Materials

An Entrepreneur

A person who happily works 16 hours a day for himself, to avoid working 8 hours a day for someone else.

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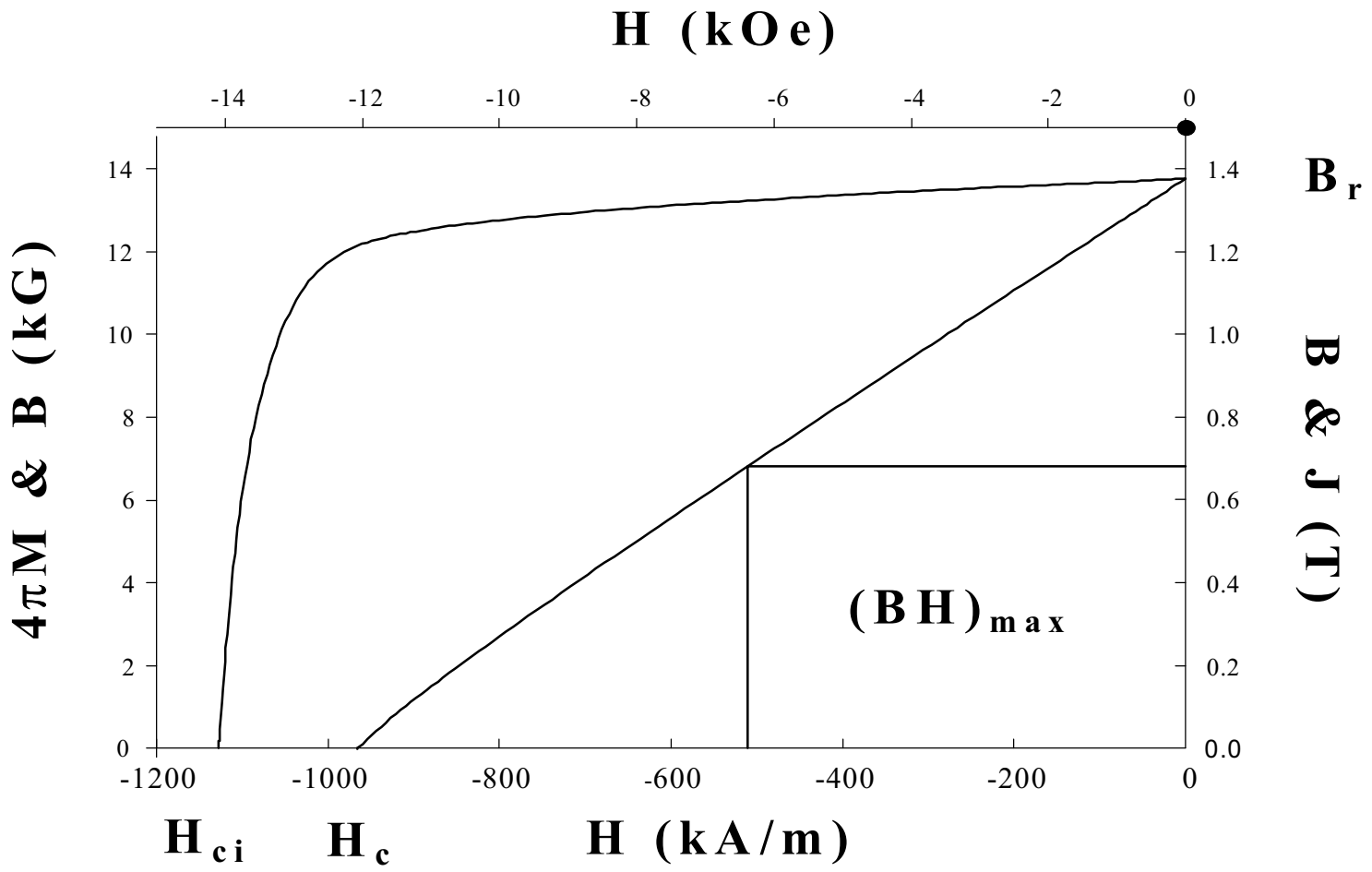
Demagnetization curves



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Four Families of Permanent Magnets

	Ferrite	Alnico	SmCo			NdFeB	
Property	Ceramic 8	Alnico 5	1-5	1-5 TC	2-17	Bonded	Sintered
B_r (kG)	4.0	12.5	9.0	6.1	10.4	6.9	13.4
α (%/°C)	-0.18	-0.02	-0.045	-0.001	-0.035	-0.105	-0.12
$(BH)_{max}$ MGOe	3.8	5.5	20	9	26	10	43
H_{ci} (kOe)	3.3	0.64	30	30	25	9	15
β (%/°C)	+0.4	-0.015	-0.3	-0.02	-0.3	-0.4	-0.6
H_s (kOe)	10	3	20	40	30	35	35
T_c (°C)	460	890	727	729	825	360	310

Notes:
The quantity α is the reversible temperature coefficient of B_r. (20 °C to 100 °C minimum)
The quantity β is the reversible temperature coefficient of H_{ci}. (20 °C to 100 °C minimum)
The field required to saturate the magnet is H_s.
TC means temperature compensated. [References 1, 2]

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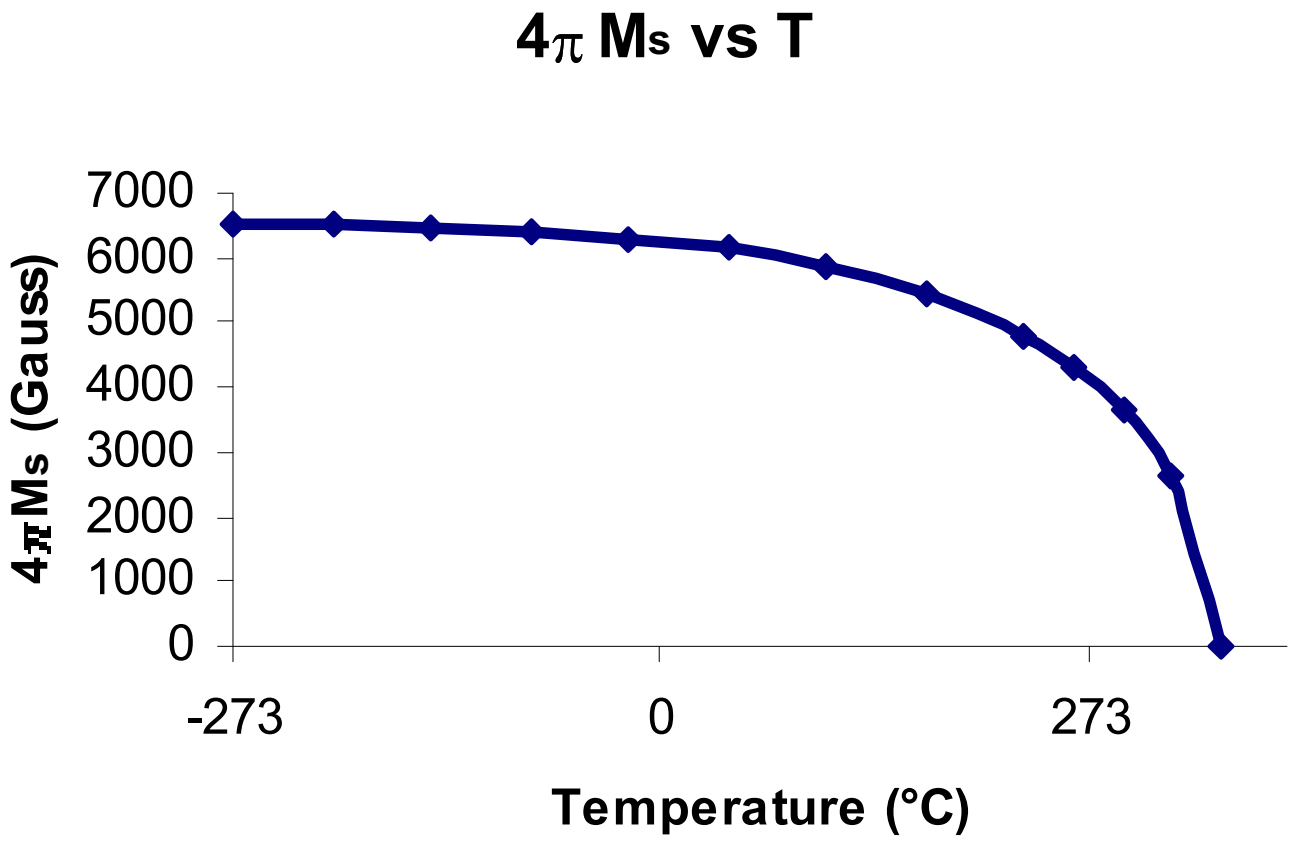
Curie Temperature



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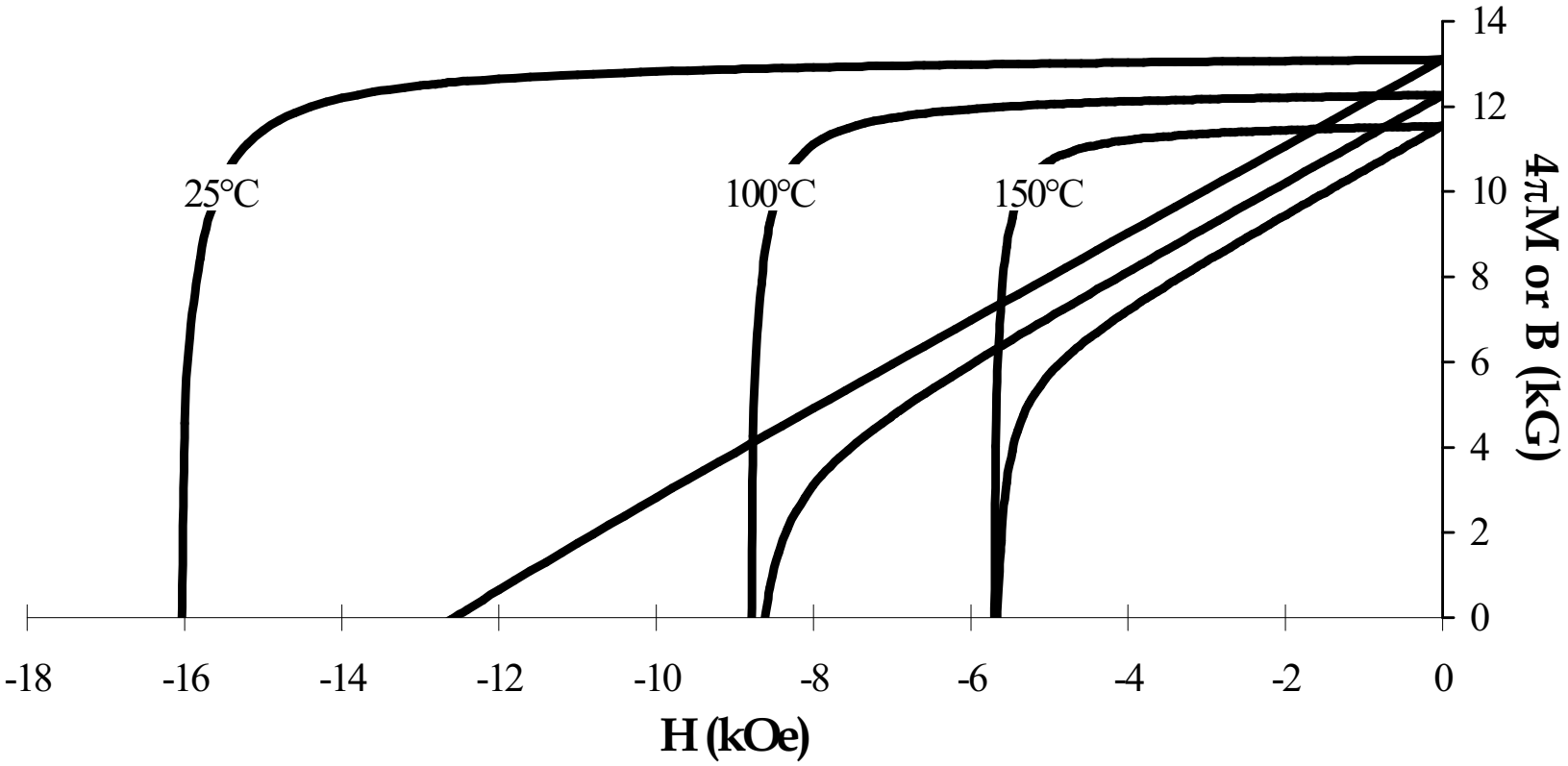
Reversible Temperature Coefficients

- $\alpha = 1/B_r \, (\Delta B_r/\Delta T) \times 100\%$
- $\beta = 1/H_{ci} \, (\Delta H_{ci}/\Delta T) \times 100\%$

Demagnetization Curves @ Temp.



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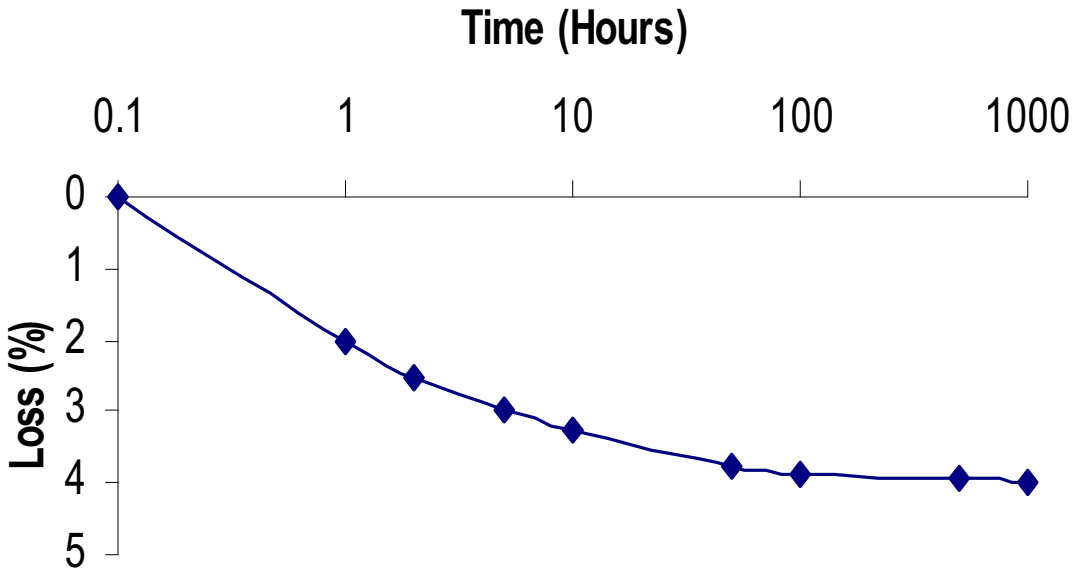
Irreversible Loss



Key parameters

- Temperature
- Time
- Loadline, self demagnetization
- Adverse field, armature reaction

Comments

- Logarithmic
- Recovered be remagnetization
- Properly saturated

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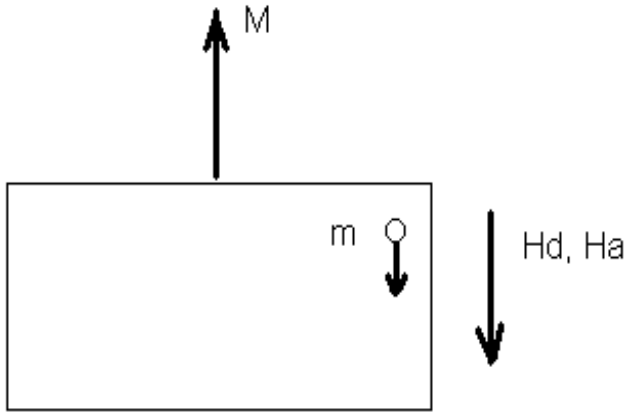
Structural Loss

- Structural losses are <u>not</u> recovered by remagnetizing
- Both due to a thermal event
- May be lumped together



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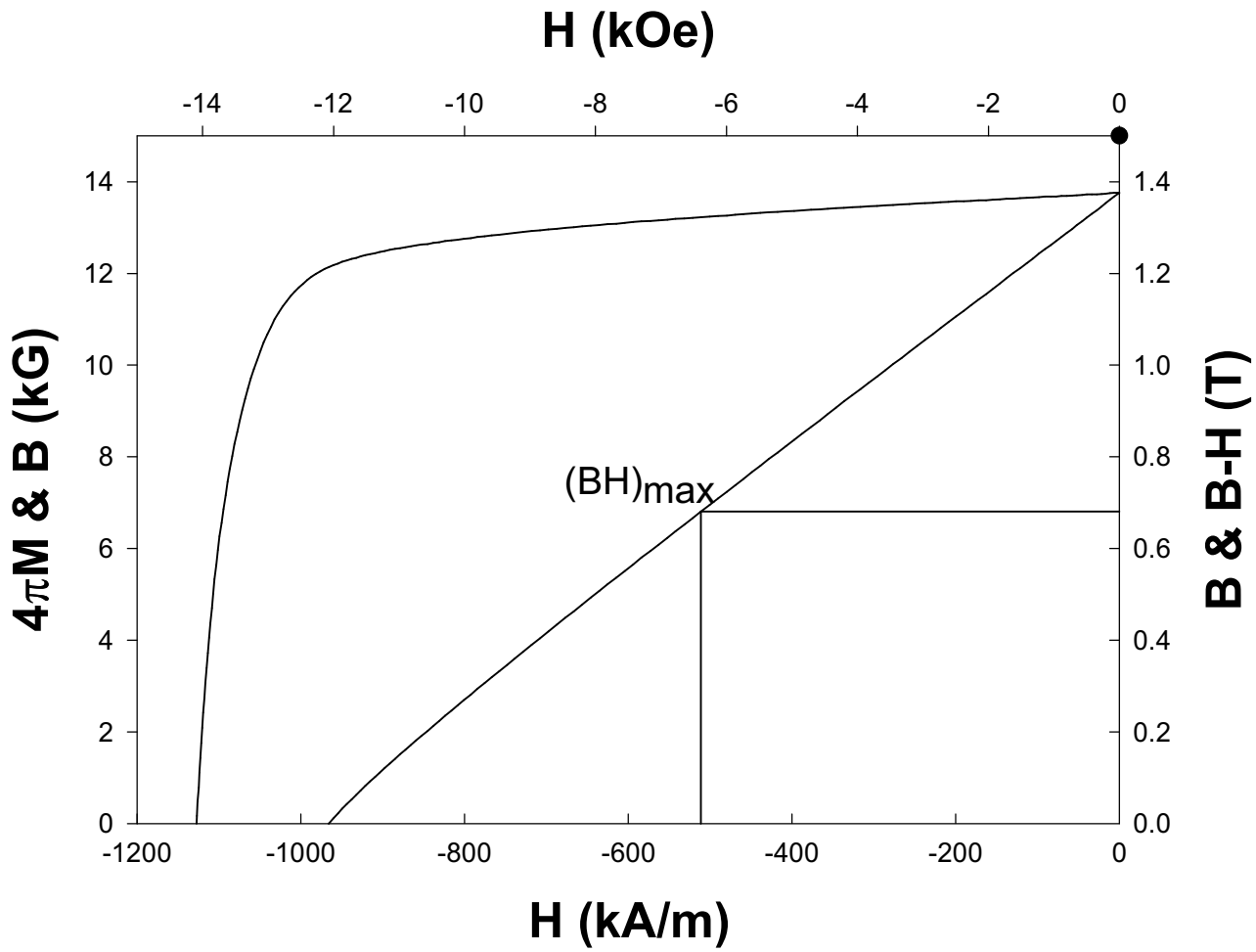
Maximum Operating Temperature

- No standard definition
- Loss or linearity?
- More confusing than helpful

A proposed definition

The highest temperature where the B vs. H curve remains linear from B_r to B/H=1, *and* where the irreversible losses at B/H=1 flatten out over time, i.e. show essentially no additional irreversible loss after 100 hours.

H_{ci} as a "Thermal" Property



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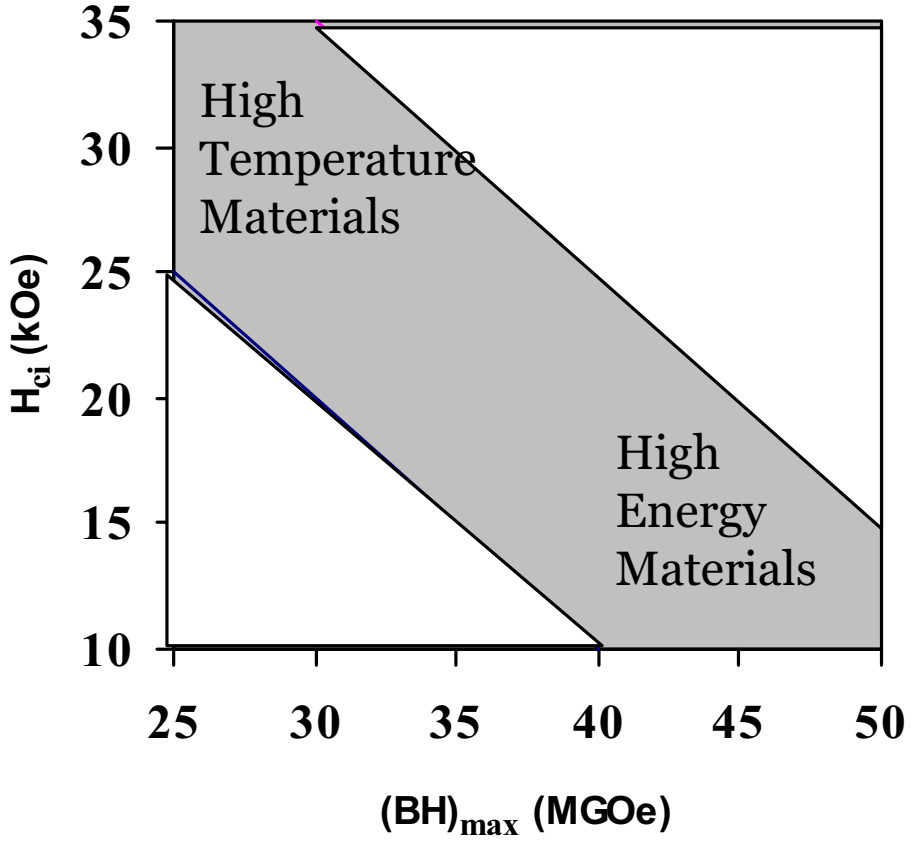
H_{ci} as a "Thermal" Property



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Summary

Parameter	How used?	Comments
Curie temperature, T_c	Absolute temperature limit	Helpful for material development, not helpful for designers
Reversible temperature coefficients, α, β	Estimate curves at temperature when data not available	Good tools
Demagnetization curves at temperature	Model performance at temperature	Fundamental data, essential for modeling
Irreversible loss	To de-rate curves at temperature for accurate performance estimates	Very design specific
Structural loss		
Maximum operating temperature	To compare materials	No standard definition, dangerous to use without considering definition
Intrinsic coercive field, H_{ci}	To compare materials	Not as useful as other parameters

Conclusions

- Understand thermal envelope of the design
- Consider magnet thermal properties as an integral part of the design process
- Prioritize thermal behavior, i.e. low irreversible loss, best curve at temperature, etc.
- Remember demagnetization curves at temperature and irreversible loss are typically the most important characteristics
- The industry needs to adopt a standard definition for Maximum Operating Temperature