The Buckling of Fuel Rods in Transportation Casks under Hypothetical Accident Conditions

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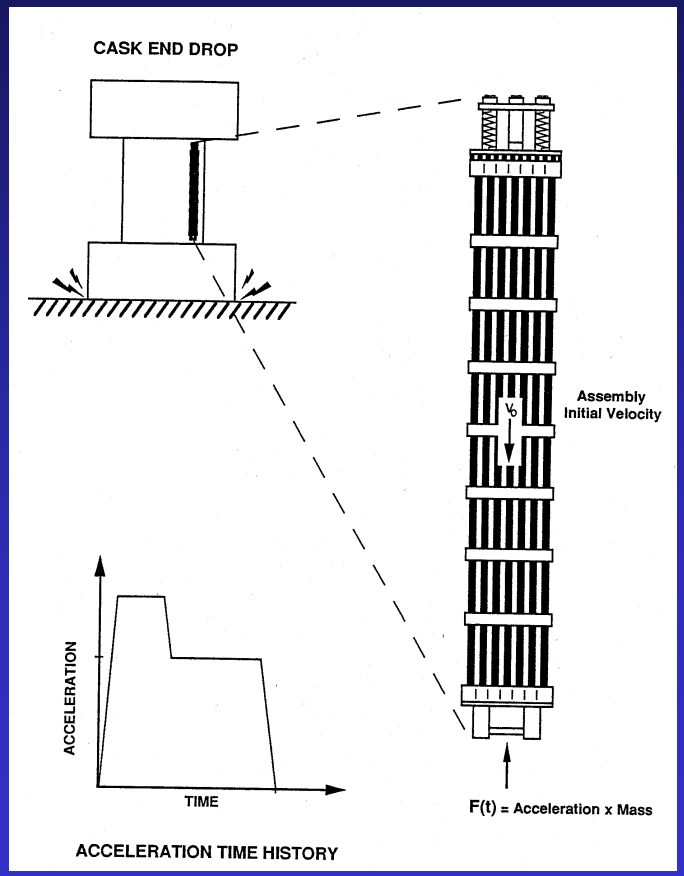
Presentation Outline

- Cask Impact
- Buckling Geometry
- Closer Look at the Fuel Rod
- Different Sources Predict Different Buckling Loads
- Overview of the Buckling Problem
- Solution Approach: Begin from First Principles
- Enforce Lateral Displacement Compatibility
- Exact Solution
- Conclusion

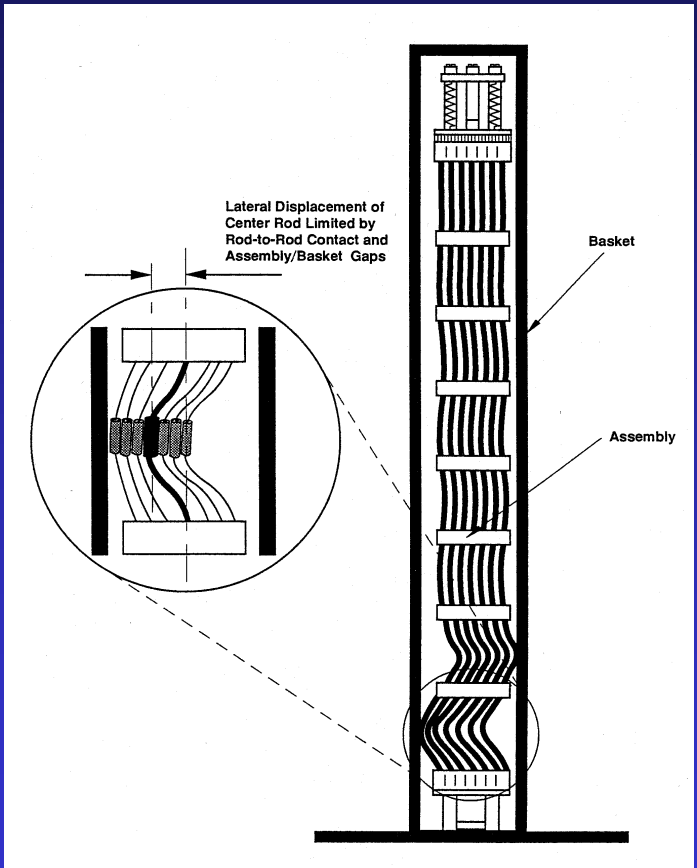
Cask and Fuel Assembly Impact under 9.0 meter Drop

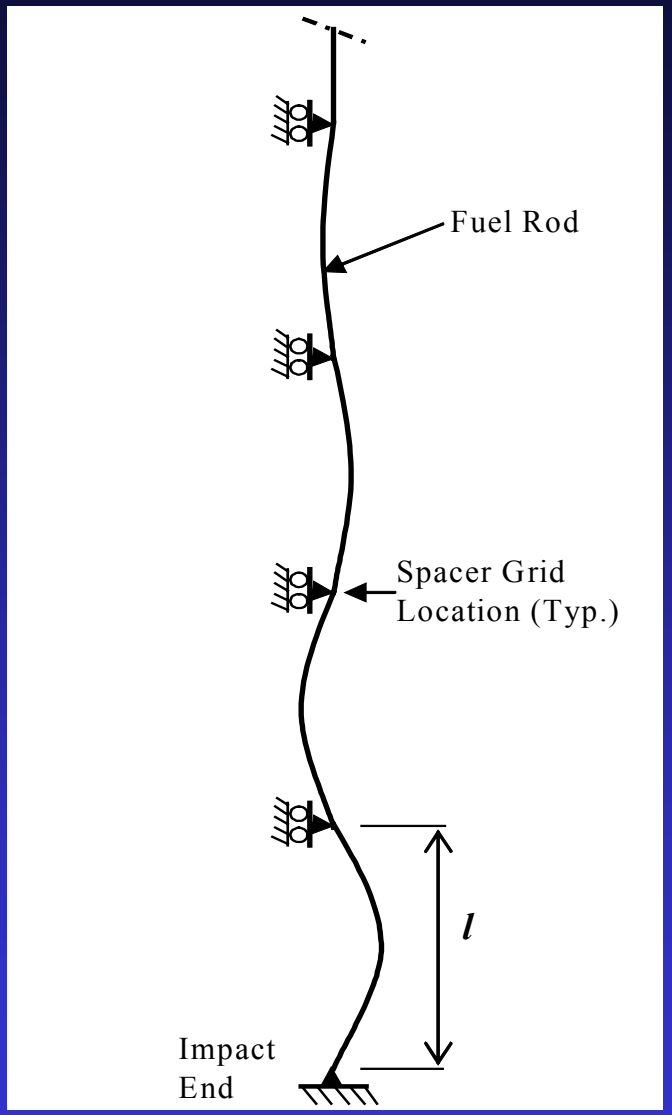
(Figure Courtesy Sandia National Laboratory)



Fuel Rod Buckling under 9.0 meter Drop Impact

(Figure Courtesy Sandia National Laboratory)





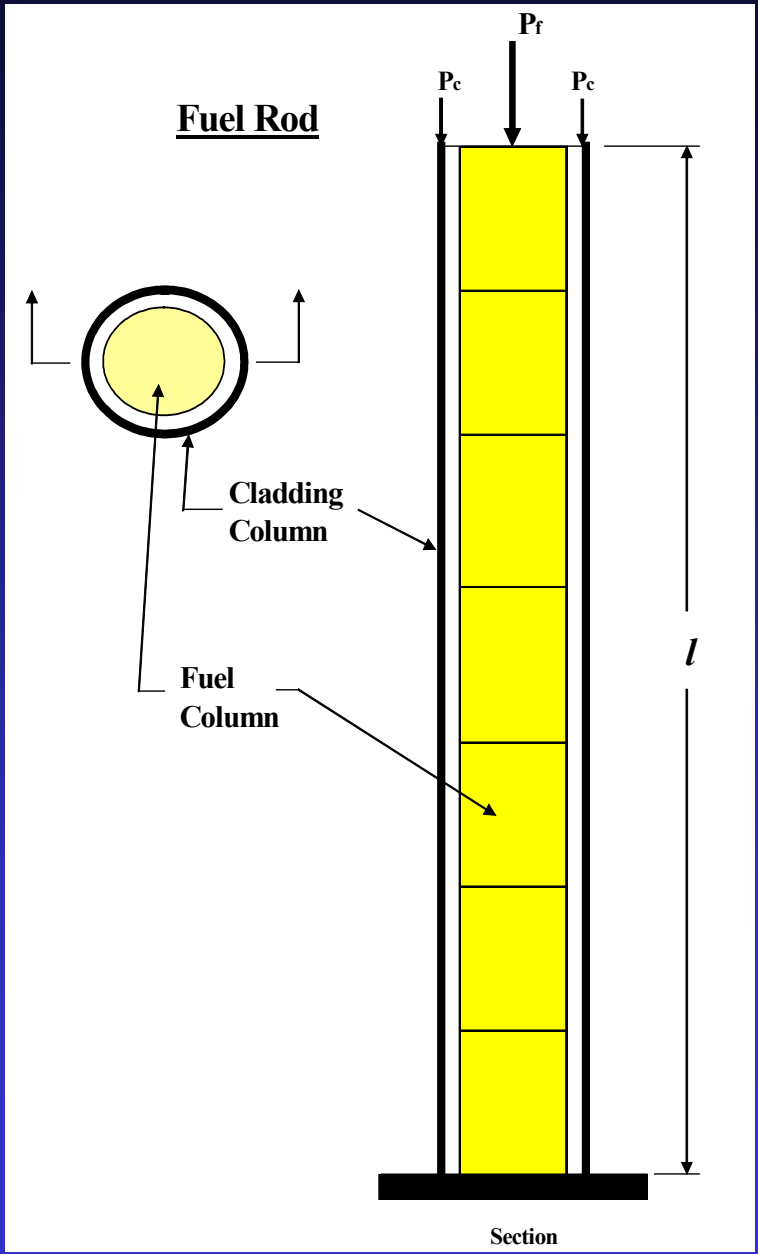
The Buckling Problem

- Fuel rod buckled shape under end drop impact
- What is the inertia load (the “g” load) at which buckling occurs?

Closer Look

Fresh Fuel - Fuel not bonded to cladding

Spent Fuel - Some % of fuel bonded to cladding



Dilemma: Different Sources Predict Different Buckling Loads

Source	Assumptions		Buckling Load (g's) Note 1
	Buckling Resistance	Fuel Participation	
Reference 2	Cladding Column Only	No Fuel Participates with Cladding (No Fuel Bonded to Cladding)	100 g Note 2
Reference 3	Cladding Column Only	10% of BWR Fuel Bonded to Cladding 75% of PWR Fuel Bonded to Cladding	71 g 25 g
NRC References 4 & 5	Cladding Column Only	100% of Fuel Participates with Cladding	20 g

Note 1: Buckling load calculation assumes fuel is 80% of total fuel rod weight.
Note 2: Value arbitrarily selected for illustration only

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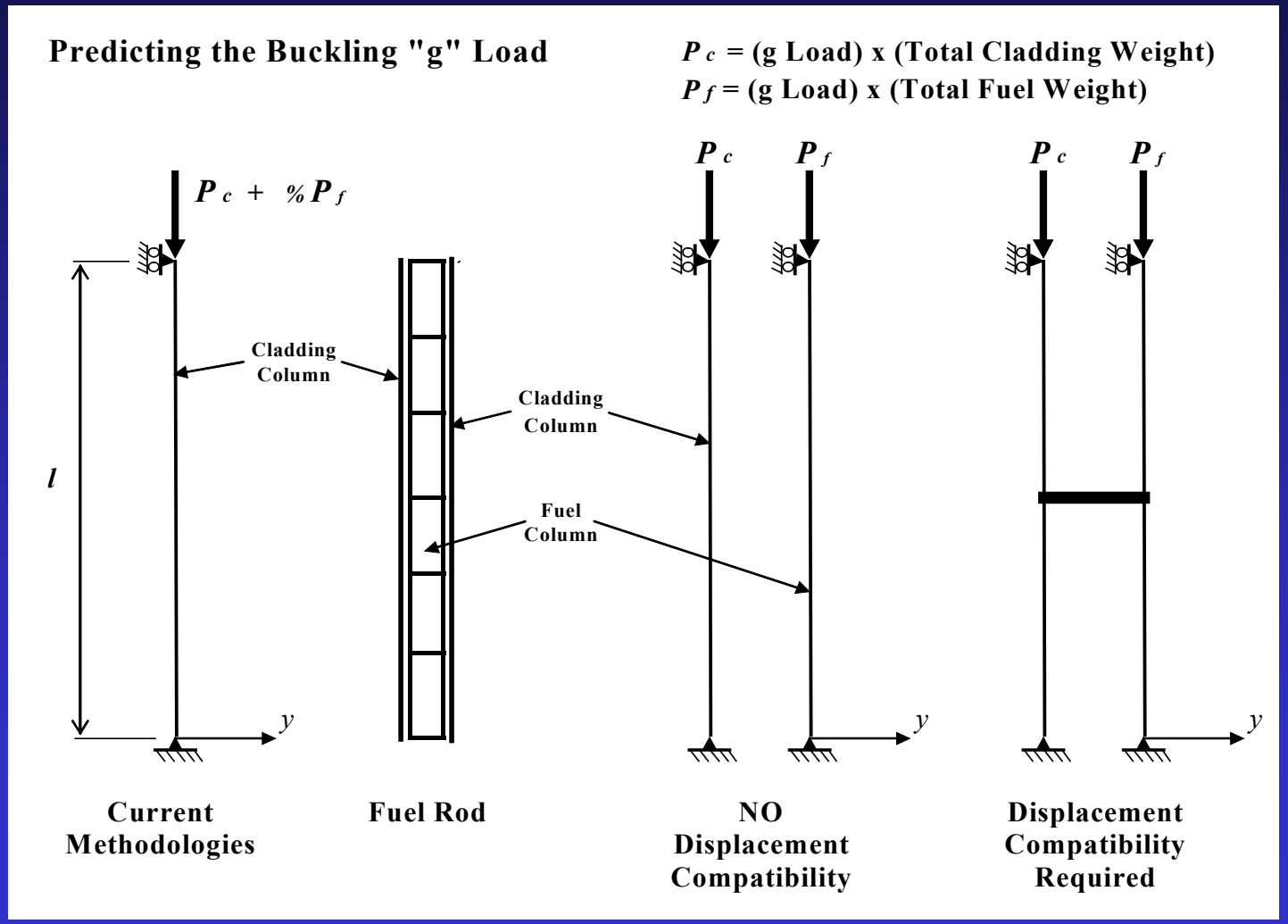
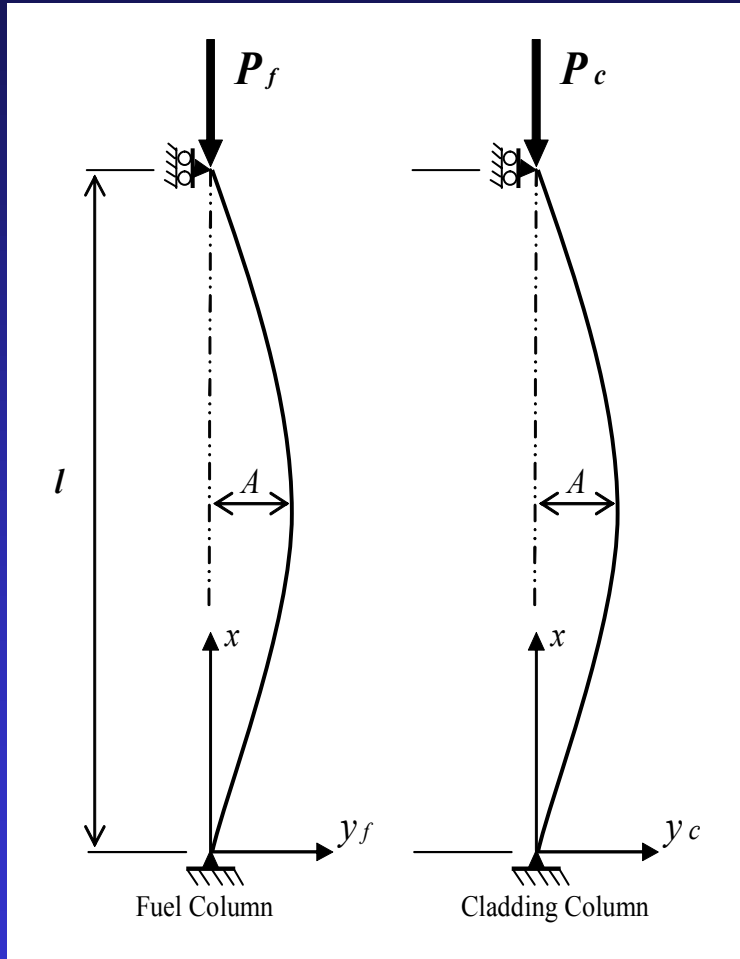
Overview of the Buckling Problem



$P_c = \alpha W_c$
$P_f = \alpha W_f$

Solution Approach: Begin from First Principles



Let α = Inertia Load in g's

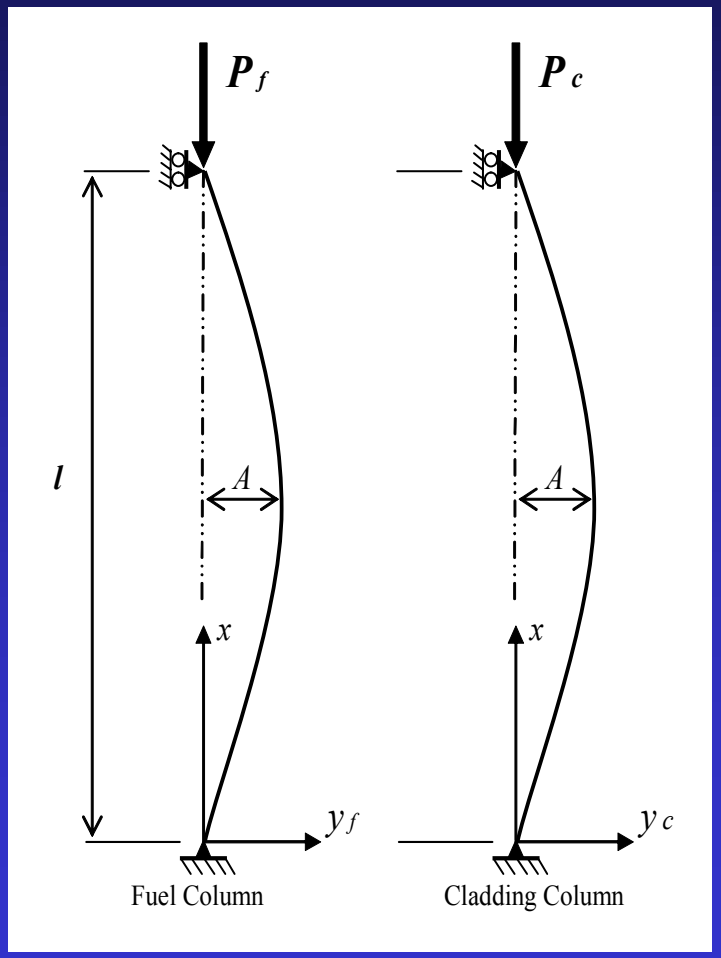
$$P_c = \alpha W_c$$

$$P_f = \alpha W_f$$

$$E_c I_c \frac{d^4 y_c}{dx^4} + \alpha W_c \frac{d^2 y_c}{dx^2} = 0$$

$$E_f I_f \frac{d^4 y_f}{dx^4} + \alpha W_f \frac{d^2 y_f}{dx^2} = 0$$

Enforce Lateral Displacement Compatibility



Enforce Compatibility

$$y_c = y_f = y$$

Resulting Differential Equation

$$(E_c I_c + E_f I_f)\frac{d^4 y}{dx^4} + \alpha(W_c + W_f)\frac{d^2 y}{dx^2} = 0$$

Solution

Final Solution for Critical Inertia Load

$$\alpha_{cr} = \frac{\pi^2}{l^2} \frac{(E_c I_c + E_f I_f)}{(W_c + W_f)}$$

Assuming Fuel does Not Contribute to Buckling Resistance, $E_f I_f = 0$

$$\alpha_{cr} = \frac{\pi^2}{l^2} \frac{E_c I_c}{(W_c + W_f)}$$

Conclusion

100 % of the Fuel Always Participates in the Buckling of a Fuel Rod under Inertia Loading.