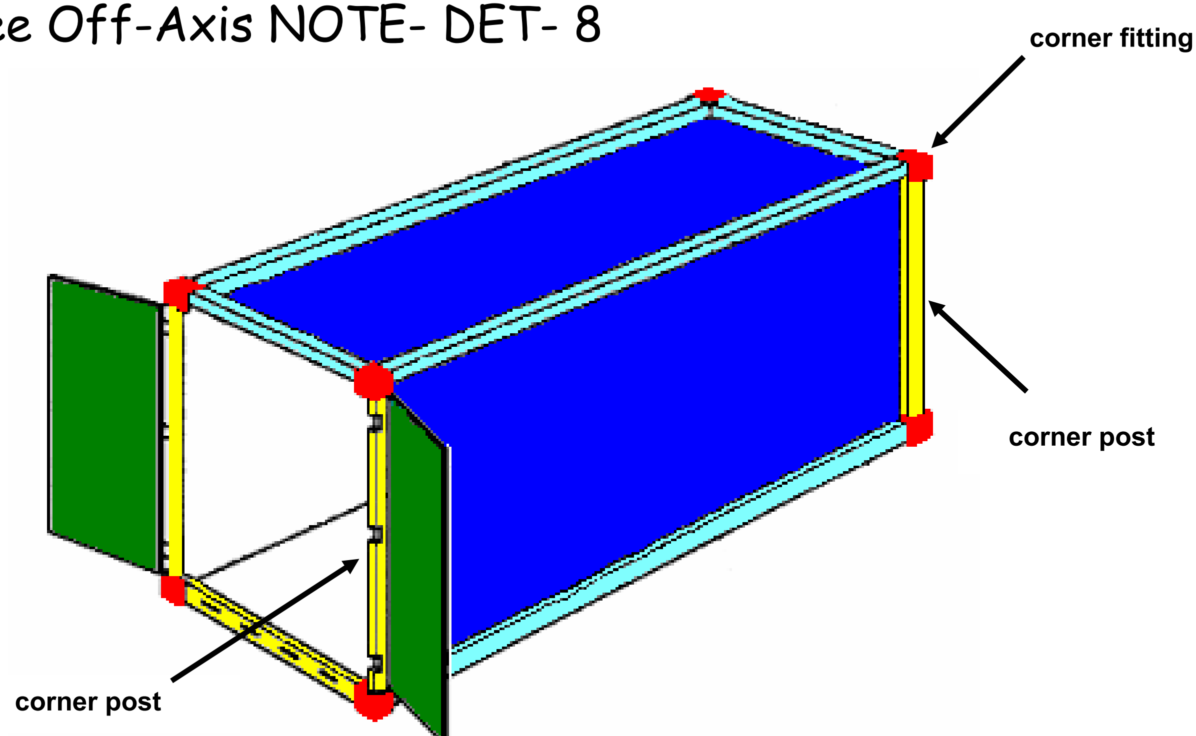
Possible Options with Containers

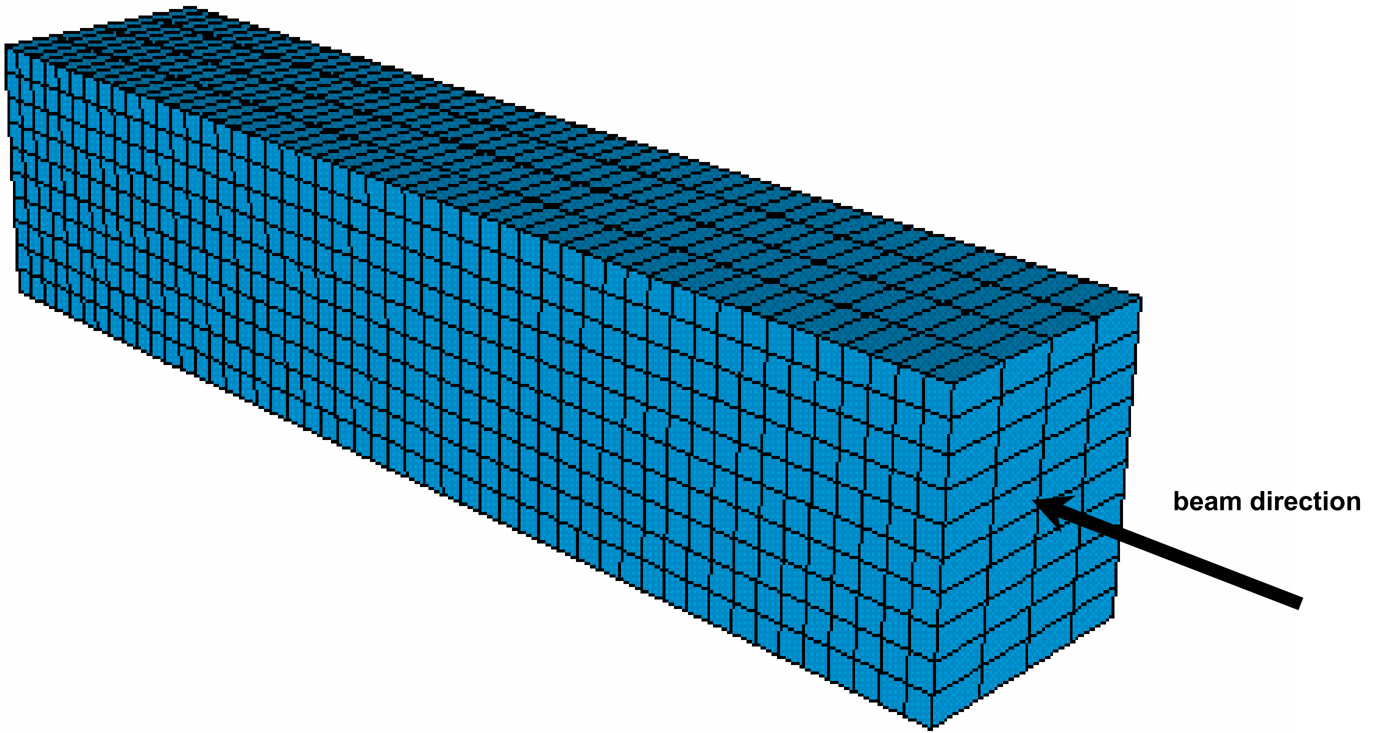
John Cooper
Fermilab Off-Axis Workshop
July 11, 2003

- Recall the standard shipping containers
  - Stack so only the corner fittings touch
  - The corner posts take the load,
    but the side skins play a role in keeping the posts vertical
  - Can be stacked 10 high with a payload density of 0.75 g/cc
    - See Off-Axis NOTE- DET- 8



50 kTons with containers

- 4 wide by 10 high by 50 deep
  - 2000 containers, each with about 25 tons
- Today focus on
  - additional thoughts about the horizontal and vertical cracks seen by the beam
  - And on the absorber material inside the strong containers



Recall that to service the containers after stacking, we propose using cell guides just like on container ships

- These create a vertical crack

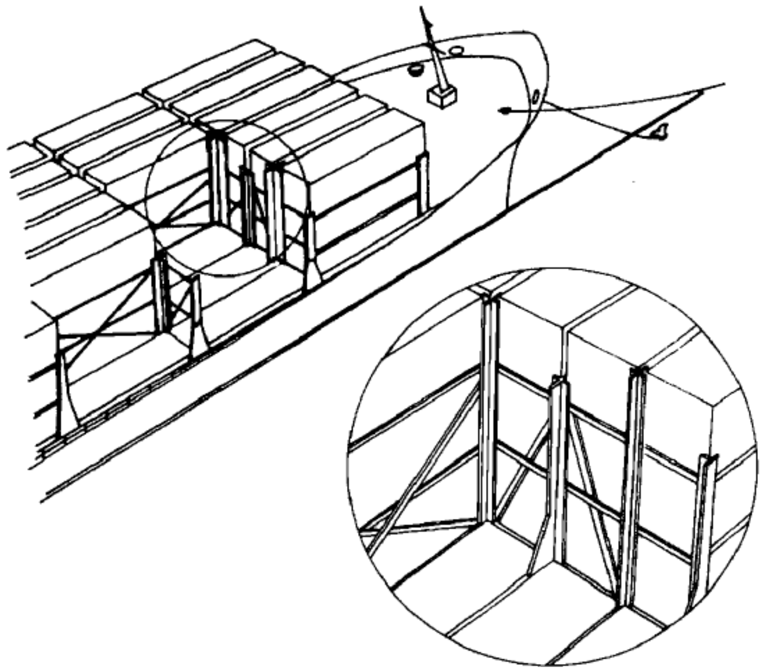
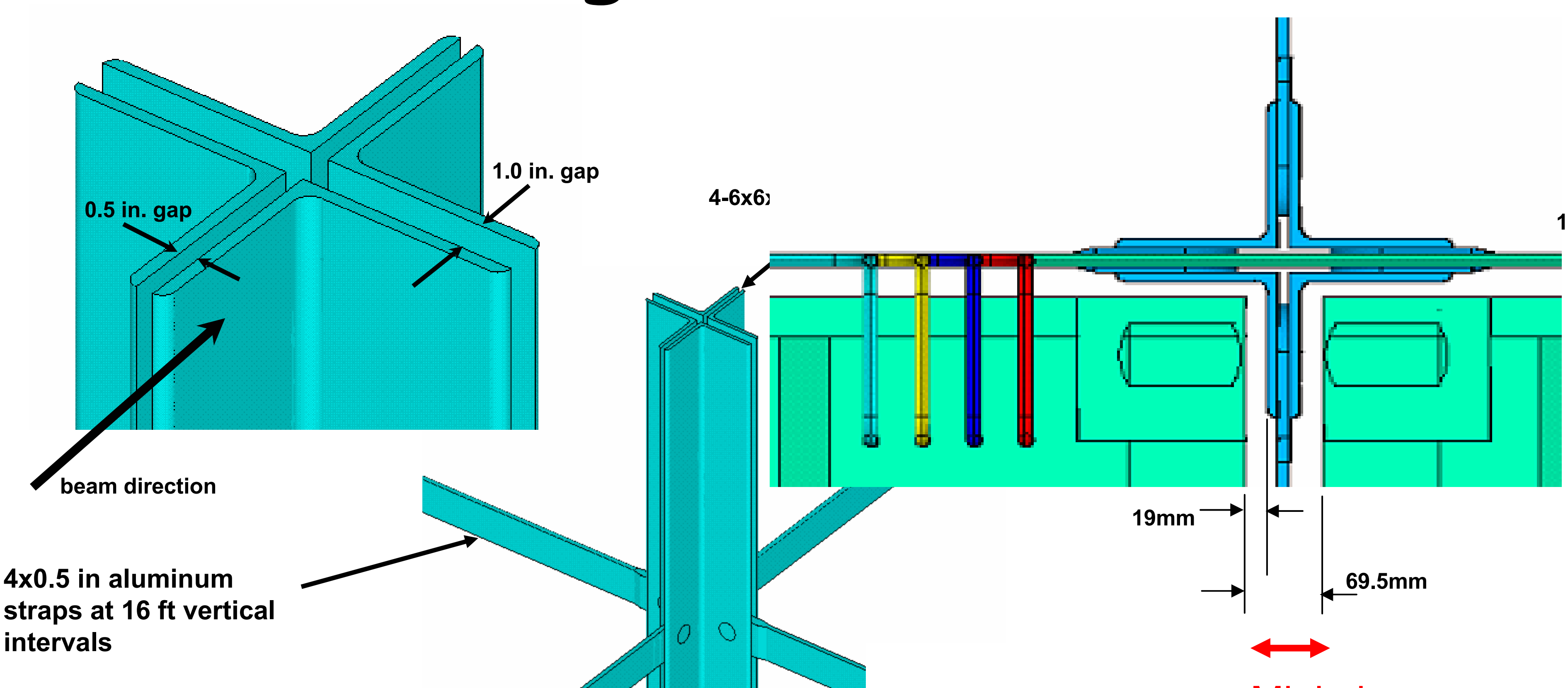


Figure 2. Container ship cell guides ***(from ISO Standards Handbook "Freight Containers", Third Edition)***

Minimizing the Cell Guides

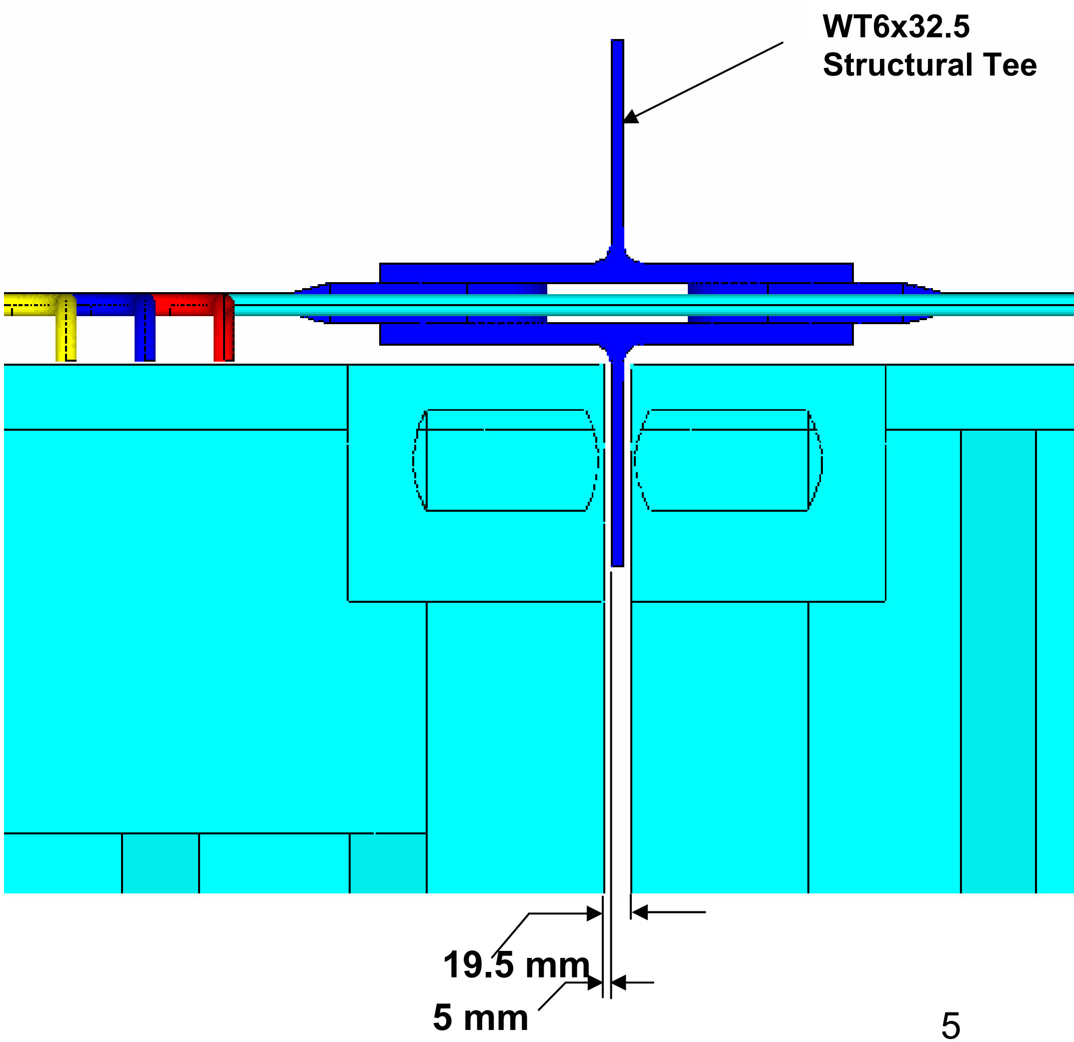


Minimize
This 70 mm gap

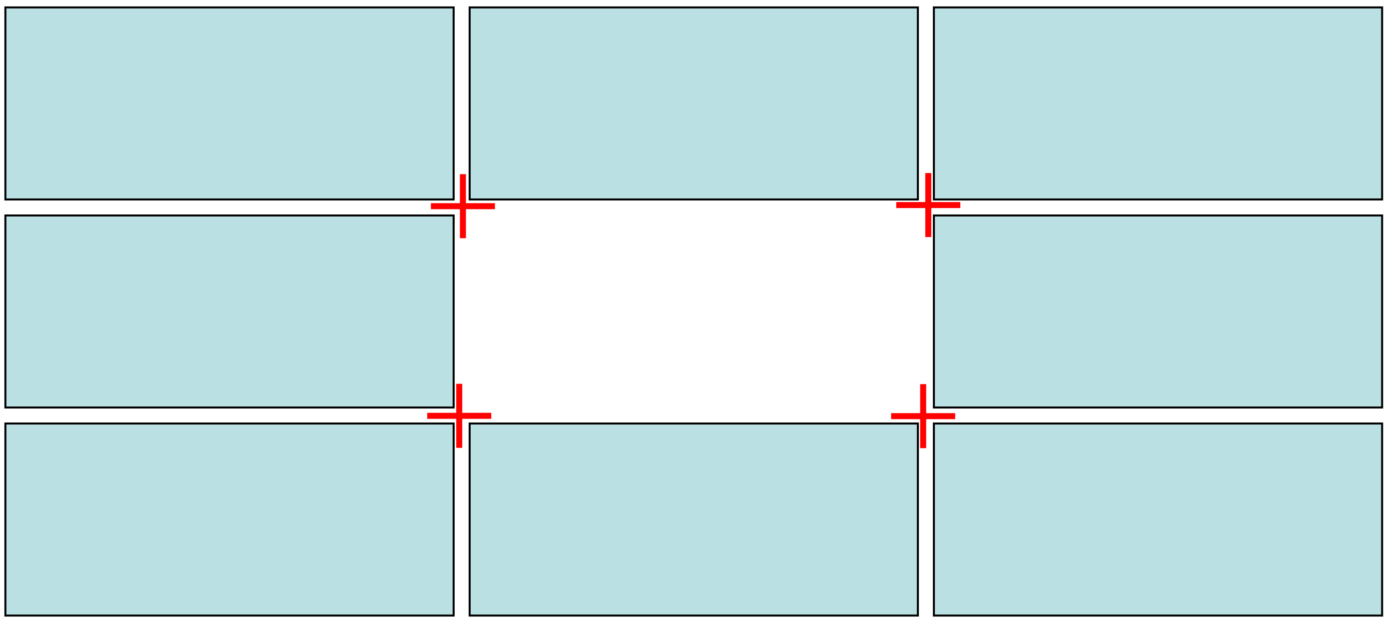
- First pass followed ISO clearances
    - Which were designed for speed, not that is not our problem
- Changes:
    - **back-to-back angles become structural tees**
    - **Remove straps**
        - they can be bolted on during assembly, removed when containers appear
    - **Reduce container to cell guide clearances**

New Cell Guides

- Old:
  - Corner block to corner block was 69.5 mm
  - Container outside to cell guide was 19 mm
  - **Container inside edge to inside edge was 229 mm**
- New:
  - Corner block to corner block is 19.5 mm, **remove 50 mm**
  - Container outside to cell guide is 5 mm
    - Take advantage of +0,-6mm container length spec
    - Add Teflon to corner blocks to prevent jamming?
  - **Container inside edge to inside edge is 179 mm**



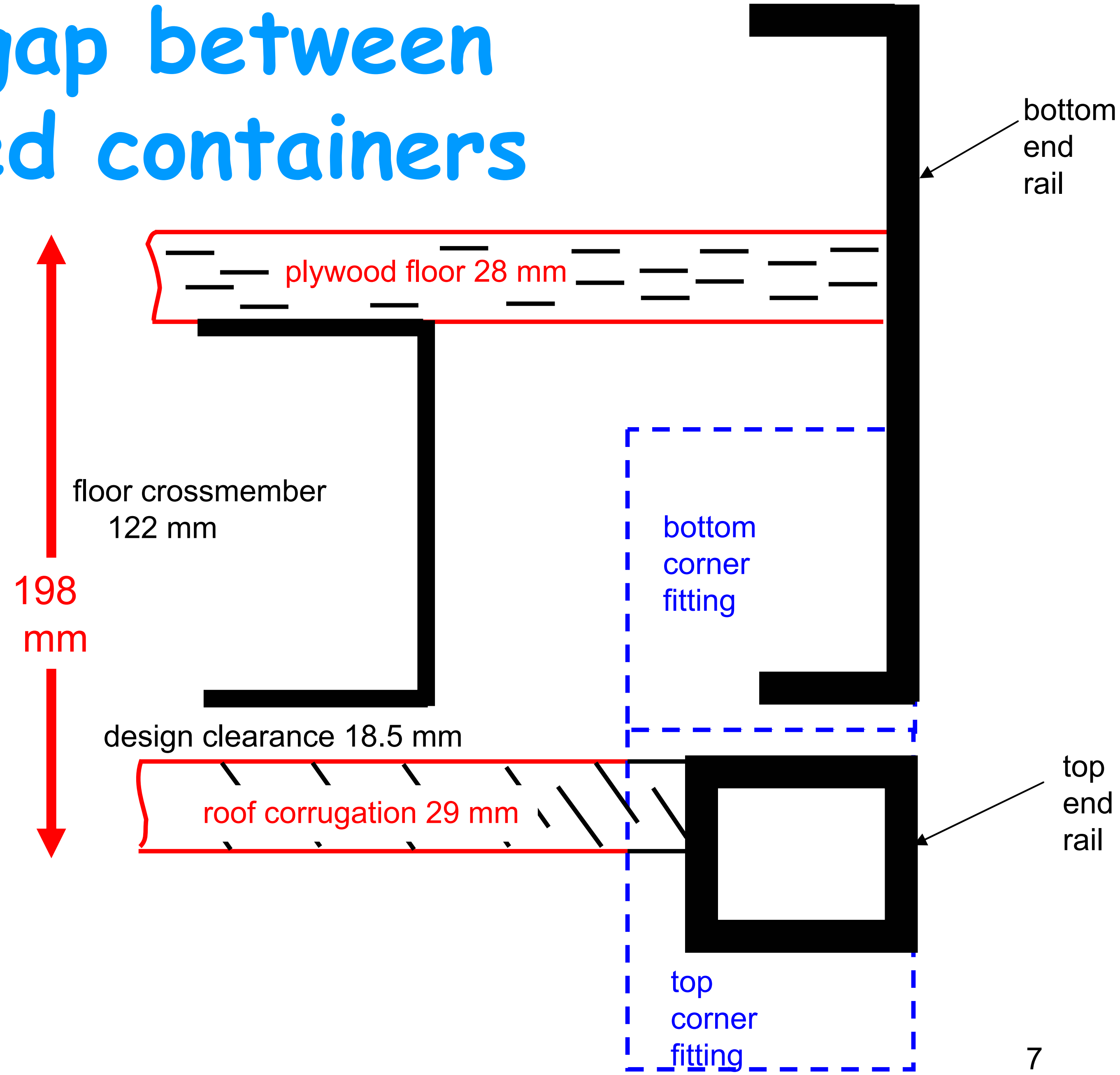
New Cell Guides



- Top view diagram
- Once installed, the cell guides can't move if we are removing only one stack to service one container
  - So none of the straps are required AFTER assembly

The gap between stacked containers

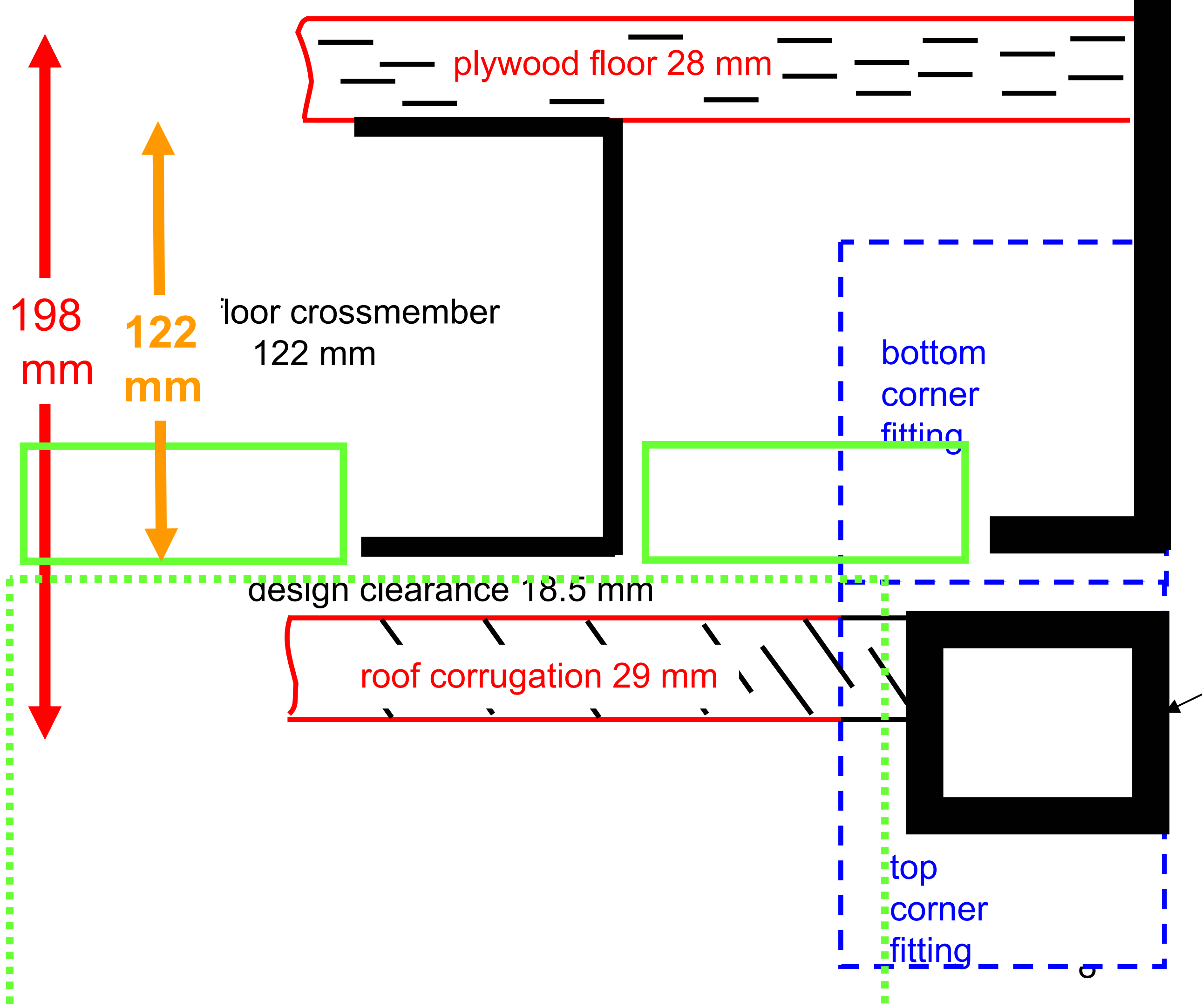
- ISO spec is < 241 mm
- Typical vendor is 198 mm
- What can we remove?



Minimizing the gap between stacked containers

- What can we remove?
  - Roof is easy
    - Weather tight implications, replace with tarp
  - Plywood floor
    - There for forklifts
    - Weather tight implications, replace with thin metal?
  - Most of the clearance
    - sag under full load is only 5 mm
- Many of the cross members, maybe all but one or two?

- **198 → 122, perhaps as low as 5 mm ?**



Alternate Absorbers?

- It has come to my attention that some people view the cost of containers as an “extra” & “unnecessary” expense
  - **My view is different,**
    - that the containers provide the ideal structure for a large detector
    - that monolith particle board structures will require widgets and labor such that the containers will look cheap
  - **However, I note that we don’t need the strength of particle board in containers**
    - So maybe there are less strong, but cheaper absorbers which might offset the perceived “extra” cost ?
    - And take full advantage of the container strength
- EOI discussed granular options
    - Cracked Corn, walnut shells, shredded tires
    - But cost of interior partitions ????
    - So mostly I will stick to other building materials
- Of course must understand the radiation length of alternates

So far our default is Particle Board

- Specific Budgetary estimates
  - 14.1 cents a pound delivered in MN (B. Choudhary)
  - 11 cents a pound at the plant gate (C. Bromberg)
- 46.4 kTon required (Adam Para, ANL Workshop)
  - This is about $ 13 M (Jeff Nelson, ANL Workshop)
- So if another solution is 1 cent per pound less, could save about $ 1 M

What about $Ca\ SO_4\ 2H_2O$?

- **Calcium Sulfate Dihydrate is Gypsum**

- **This is the core material in drywall or sheetrock**
  - Widespread building material
    - Crush gypsum, dry it to remove all the water, add water again to get a paste / slurry ("Plaster of Paris"), add a paper wrapper to the top and bottom of a thin sheet, and the whole thing sets up in minutes. Slice it and dry it thoroughly.
  - Density is 0.68 g/cc
  - Score paper wrapper and snap to size
  - nail in place
  - typically 4' x 8' , but up to 4' x 16'
  - Available thickness: $\frac{1}{4}$ to 1", but $\frac{1}{2}$" is most common – see samples
    - Controlled to +- 1/64" or 0.4 mm

- **What's the cost, what's the radiation length?**

Budgetary Estimate for 50 kTon of Drywall

- The 1st US Manufacturer's National Headquarters steered me to their Midwest regional sales office
  - They gave it 30 seconds thought and said
    - **11 cents a pound delivered anywhere in the US**
- Having saved $ 3 M with one call, I called A 2nd US Manufacturer, & after a day they said
    - **9.5 – 10 cents a pound delivered**
- Encouraged, I called a 3rd US Manufacturer headquarters who steered me to regional distributors:
  - One local group who deals in 50,000 lb truckloads thought 50 kTons was "a lot", but after 3 days got back to me with
    - **9.1 cents a pound + "nominal delivery"**, they do 8 * 50,000 lb truckloads a day
  - Another vendor who handles 200,000 lb railcar loads found 50 kTon "interesting"
    - **7.8 cents a pound**, but would add additional delivery charge
- Then one weekend, I went to my local **Home Depot** store in Geneva
    - Who will sell to anyone at **6.6 cents a pound** (5/4/03 for 4' x 12' x 5/8")
    - and claim to always have 1000 sheets in stock
    - AND, they have 10% contractor discounts available !
- I called the 1st guy back & asked "WHY?", did I miss by packaging factor of 2?
    - No, "not serious yet, so did not give best price"
    - Sell to 800 Home Depot stores and our 50 KTon request is "small"
      - Aside: Home Depot actually has 1600 stores, probably play one vendor against another

Budgetary Estimate for Drywall

- Have since learned there are 80 plants in the US with a production capacity of 36 billion sq ft a year.
  - At typical 2.1 lbs/sq ft this is 38 megatons
  - So our measly 50 kTon is 0.13 % of the annual US output of drywall
- So I believe the base price for drywall is less than 6 cents a pound
  - Find similar prices at Menard's and Lowe's and Home Depot
  - Implies savings of $ 7.5 M relative to the 14.1 cent/lb particle board
    - Maybe less -- still probably want to wrap the RPCs in particle board
  - But the savings is about twice the cost of the containers
- **Quick!** a Home Depot reality check on Particle Board !
  - **Find 12.2 cents a pound (5/4/03, for 4' x 8' x ¾" sheets)**
- **Seems to imply a model for construction????**
  - But don't forget the model must include transportation

Calculating Radiation Length

- Review of Particle Properties
- X_0 , to better than 2.5%, can use the formula
- $$X_0 = \frac{716.4 \text{ g cm}^{-2} \ A}{Z\,(Z+1)\ \ln(\,287/\mathrm{sqrt}(Z)\,)}$$

- Then, the Radiation length in a mixture or compound may be approximated by
- $1/X_0 = \Sigma\ (\,w_j\ .\ X_j)$
  - Where w_j and Xj are the fraction by weight and the radiation length for the j^{th} element

- Let's apply this to Particle Board

Radiation Length of Particle Board

- Components:
  - Cellulose $C_6 O_5 H_5$
  - Urea Formaldehyde $NH_2\text{-}CO\text{-}NH_2$ & $N_2 C_2 3H_2O$
  - Paraffin Wax $C_{36} H_{74}$

Component	Molecular Wt	X_j (g cm^{-2})	% by weight in mixture
Cellulose	157.1	38.5	45 (not always equal)
Urea Formaldehyde	90.1	38.9	45 (")
Paraffin Wax	650.6	37.3	10 (varies 5 - 15)
Particle Board		Use % by 38.6	wt in the mix

- Divide by the density (0.72 g/cc) to get X_0 in cm = 53.6 cm

Radiation length for Drywall

- Components:
  - Gypsum $CaSO_4 + 2\,H_2O$
  - Cellulose $C_6\,O_5\,H_5$

Component	Molecular Wt	X_j ($g\ cm^{-2}$)	% by weight in mixture
Gypsum	172.2	24.9	90
Cellulose	157.1	38.5	10 (range is 5 -15)
Drywall		Use % by 25.8	wt in the mix

- Divide by the density (0.68 g/cc) to get X_0 in cm = **37.9 cm,**
  - So with the same number of detector planes, it's like sampling at 35% of a radiation length
  - Not ideal, but worth considering

Calcium, Sulfur are problems, so look for a lighter element? Boron?

- Borax is commercially available but comes with Sodium
  (still better than Calcium)
- Hydrated Sodium Borate
  $Na_2 B_4 O_7 + 10 H_2O$
- Density is 0.88 – 0.96 g/cc
- Cost
  - WalMart 7/3/03
    - 56 cents a pound in boxes
  - US Geological Survey, 2001
    - 17 cents a pound in bags
- Density a little high, cost too high

Already boxed,
so maybe stackable,
But are the boxes full?
(not likely)

Radiation Length for Borax

- Hydrated Sodium Borate
  $Na_2 B_4 O_7 + 10 H_2O$

Component	Molecular Wt	X_j ($g\ cm^{-2}$)	% by weight in mixture
Borax	381.4	35.8	100

- Divide by the density (use 0.92 g/cc)
  to get X_0 in cm = **38.9 cm**

- Very similar to drywall

How about Concrete?

- Building material, cheap
  - \$50/cubic yard delivered in your driveway
  - Or about 1 cent a pound

- More complicated chemistry, Portland Cement:
  - 50% hydration of Tricalcium Silicate
    - $3CaO\ SiO_2 + 7\ H_2O$
  - 25% hydration of Dicalcium Silicate
    - $2\ CaO\ SiO_2 + 5\ H_2O$
  - 10% hydration of Tricalcium Aluminate
    - $3\ CaO\ Al_2O_3 + 26\ H_2O$ + gypsum below
  - 10% hydration of Tetracalcium Aluminoferrite
    - $4\ CaO\ Al_2O_3\ Fe_2O_3$ + gypsum below
  - 5% gypsum
    - $CaSO_4\ 2\ H_2O$

Radiation length of Concrete

- Easier since this one is in the Particle Data Book:
  - Radiation length is 10.7 cm
    (formula gives 9.2 cm, assuming I did it right)
  - Density is 2.5 g/cc
- So why on earth would we use it?
- Mix it with lighter materials to achieve
  a density of 0.7 g/cc (44 lbs/cubic ft)

Lightweight Concretes

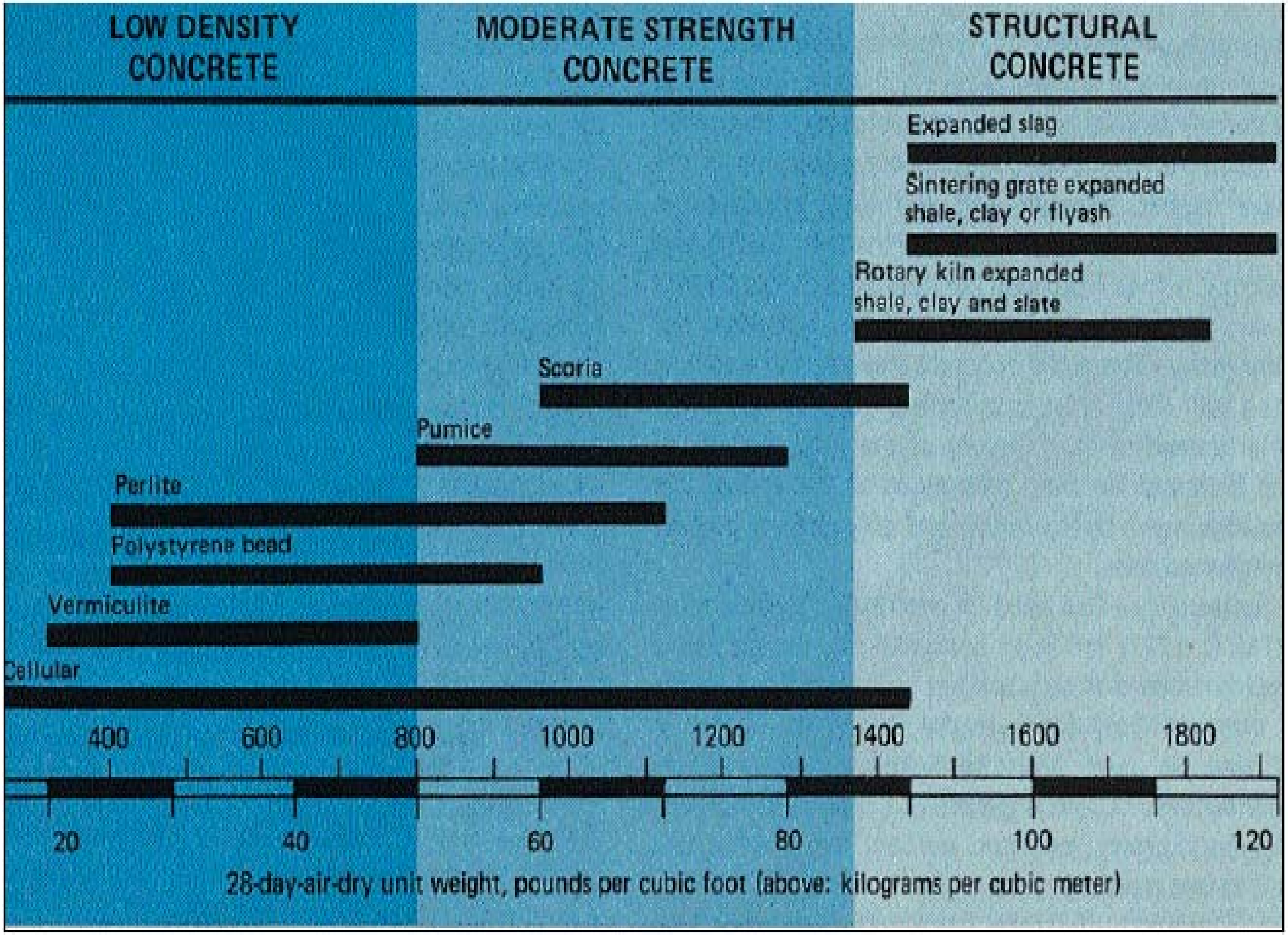
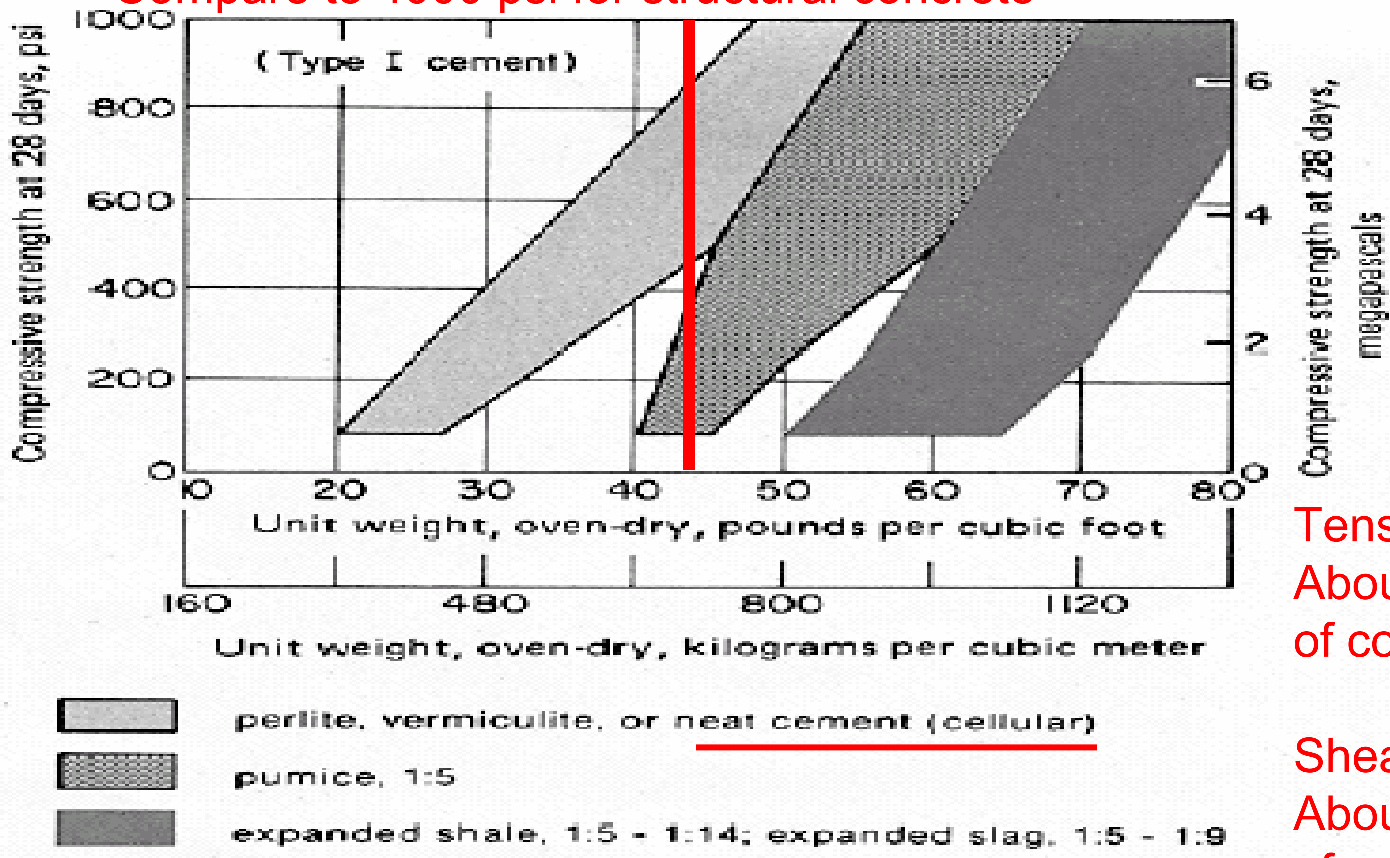


Figure 1. The full spectrum of lightweight concretes. Low density mixes discussed in this article (shaded band at left) offer best insulating properties. Chart adapted from ACI 213 report "Guide for Structural Lightweight Aggregate Concrete," *Journal of the American Concrete Institute*, August 1967, pages 433-469.

Note date

Strength of such concretes

Compare to 4000 psi for structural concrete



Tensile strength
About 25%
of compressive

Shear strength
About 5 – 10%
of compressive

Figure 3. Approximate relationship between oven-dry unit weight and compressive strength of lightweight insulating concretes tested in air-dry conditions.
Note: mix proportions for perlite and vermiculite concretes range from 1:3 to 1:10 by volume. From *Special Types of Concrete*, Portland Cement Association, Skokie, Illinois, Publication IS183T, 6 pages, 1977.

Cellular Foam Concretes

- Characterized as
  - Portland Cement + Water + shaving cream
  - "shaving cream" holds the air bubbles
- Widely used outside of the US
- Can dial in any density by adding air – see samples
- Still, at 0.7 g/cc the radiation length is
  - 10 cm *[2.5 g/cc / (0.7 g/cc)] = 35.7 cm
  - Still about like Drywall, still lots of Calcium

- One more trick to play
  - Use the least possible amount of Portland Cement and the maximum possible amount of another additive -- sand

More on Sand

- Sand: SiO_2
- Calculated radiation length is 34.3 g cm^{-2}
  - Normal dry silica sand has a density of 1.6 g/cc, so the radiation length is 21.4 cm
- But if we could get sand at 0.7 g/cc, the radiation length would be 49 cm
- Cellular Foam Concrete provides a way to reduce the density of sand and make the granular sand into a structural product

Sample Foam Concrete

- 3.5 parts sand to 1 part Portland cement
    - Density of 40 – 50 lb /cubic ft or 0.63 – 0.80 g/cc
- The radiation length for 0.7 g/cc should be about 47 cm
    - But need to check if "fully hydrated", air bubbles retard hydration
- **Ballpark Cost is in the range of 10 cents a pound**
    - Waiting for estimates from other vendors
        - Each has foam of different properties, e.g. bubble size
    - Unfortunately not sold at Home Depot
    - Must buy foam, foaming machine, mixer,.....
- Can form panels or pour in place
    - Pour in place could lead to a large savings in assembly labor

Example large panels cast in place

Or, Cast in forms, then tilt up

Summary of Alternate Absorbers

Material	**Density** (g/cc)	**Radiation** length (cm)	**Cost** (cents / lb)
Novoply	0.72	53.6	12.2 - 14.1
Drywall	0.68	37.9	6
Borax	0.92	38.9	17 - 56
Cellular Foam Concrete	0.70	47.2	10 ??? May be interesting even at this price because of labor savings

Two other topics

- **On the Fermilab detector building study**
  - Have published the report – see me if you want a copy
    - Or if you want a cool copy on a mini-CD
    - Will get posted as an Off-Axis Note
  - The fully loaded cost was $ 18.5 M
    - Included an above ground conventional steel-framed building estimated at **$2.9 M**
    - Now have two alternates
      - Pre-engineered building systems, **$ 1.6 M** and **$ 2.1 M**
      - Tension Fabric structure, metal frame, **$ 2.7 M** and **$ 3.8 M**

- **On Shipping costs of containers**
    - Next slide
    - But this information applies to shipping anything, and illustrates that we have to understand a full model of building the detector before estimating the price

Intermodal Landbridge by Rail

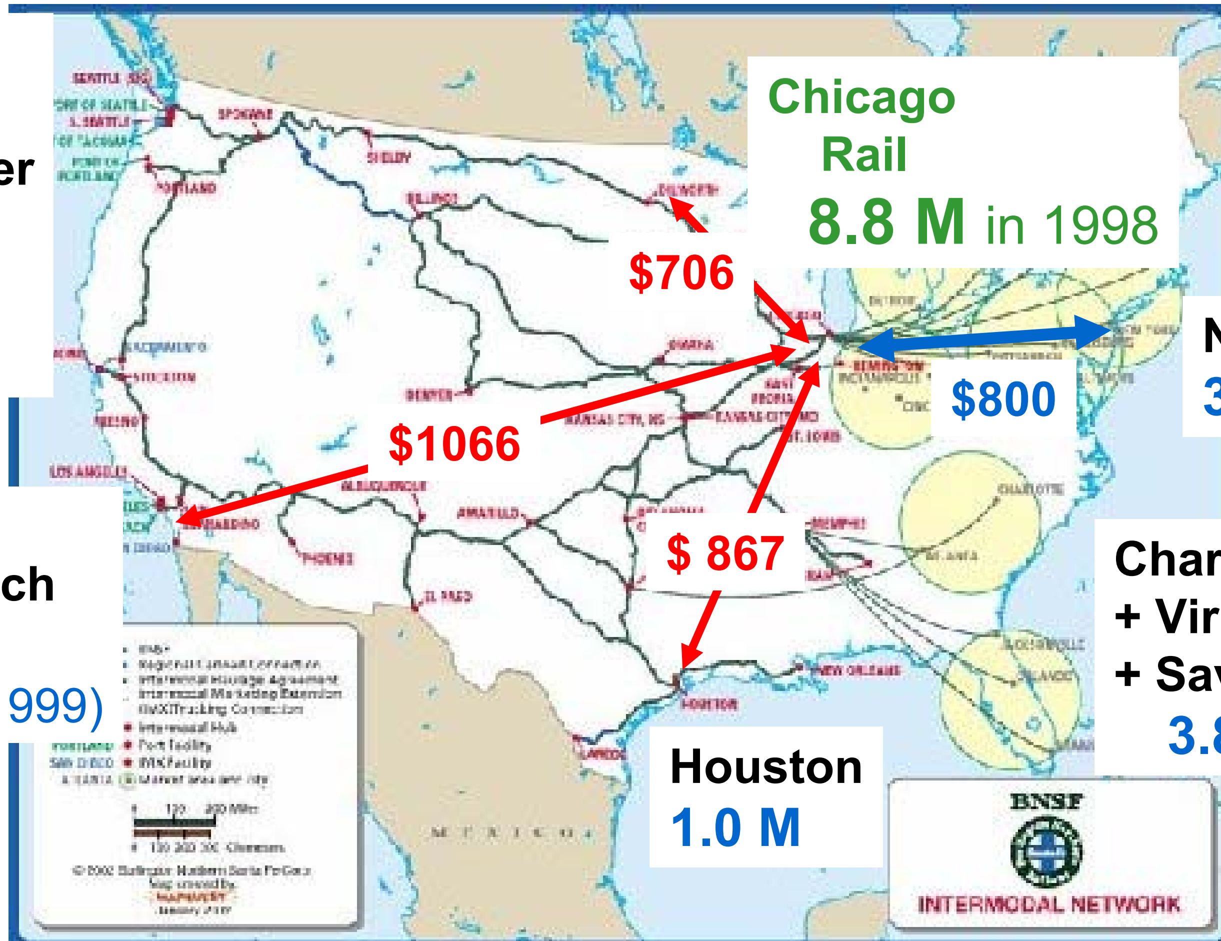
& the cost to ship a 20-foot container

WEST ⟷ **EAST**

Burlington Northern Santa Fe or Union Pacific — CSX or Norfolk Southern

Costs from BNSF website

Seattle + Tacoma + Vancouver
3.7 M TEU in 2002



Chicago Rail
8.8 M in 1998

$706

$1066

$800

$ 867

NY, NJ
3.3 M

LA + Long Beach
9.6 M
(8.2 M in 1999)

Charleston + Virginia + Savanna
3.8 M

Houston
1.0 M

I think this explains why the cost of containers is fairly uniform across the US