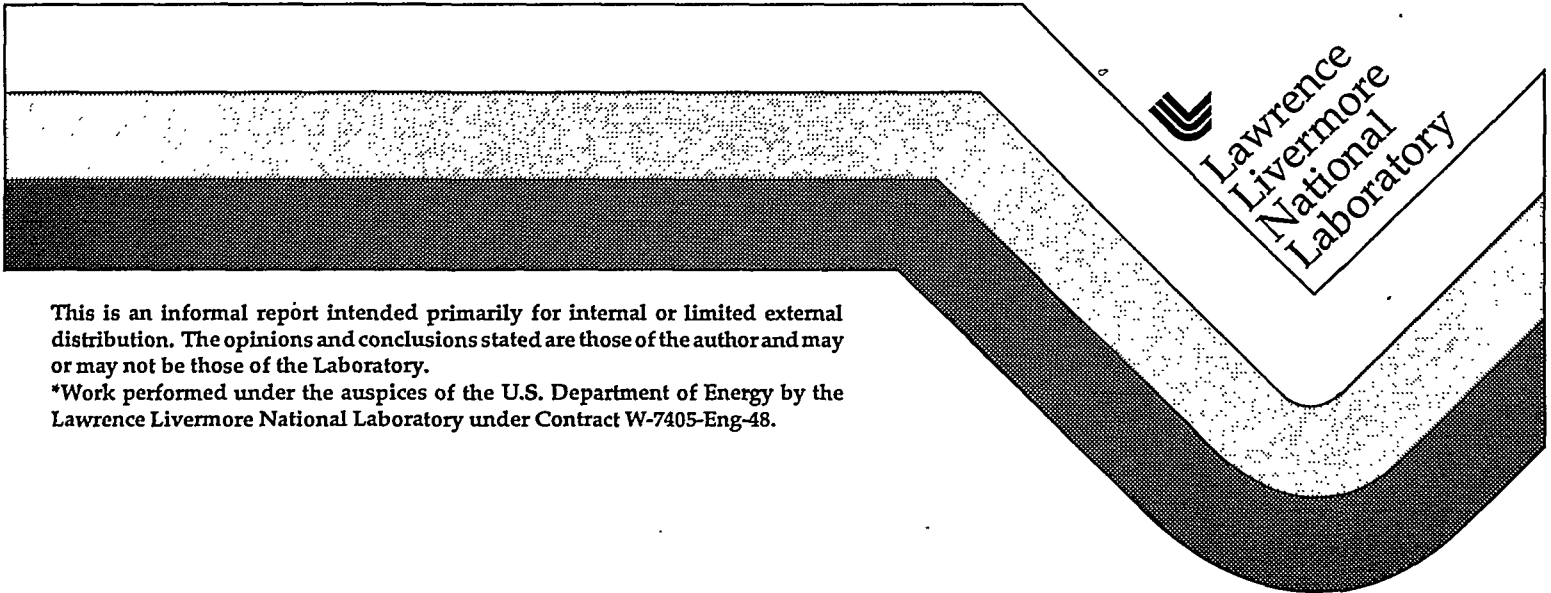


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**Final Report
NIF Laser Bundle Review***

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A.C. Erlandson, R.J. Foley, R. P. Hackel, G.L. Hermes, J.A. Horvath,
S.A. Kumpan, J.R. Murray, B.A. Remington, R.H. Sawicki,
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September 15, 1995



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FINAL REPORT NIF LASER BUNDLE REVIEW

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FINAL REPORT
NIF LASER BUNDLE REVIEW

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Summary

We performed additional bundle review effort subsequent to the completion of the preliminary report and are revising our original recommendations. We now recommend that the NIF baseline laser bundle size be changed to the 4x2 bundle configuration. There are several 4x2 bundle configurations that could be constructed at a cost similar to that of the baseline 4x12 (from \$11M more to about \$11M less than the baseline; unescalated, no contingency) and provide significant system improvements. We recommend that the building cost estimates (particularly for the in-line building options) be verified by an architect/engineer (A/E) firm knowledgeable about building design. If our cost estimates of the in-line building are accurate and therefore result in a change from the baseline U-shaped building layout, the acceptability of the in-line configuration must be reviewed from an operations viewpoint. We recommend that installation, operation, and maintenance of all laser components be reviewed to better determine the necessity of aisles, which add to the building cost significantly. The need for beam expansion must also be determined since it affects the type of bundle packing that can be used and increases the minimum laser bay width. The U-turn laser architecture (if proven viable) offers a reduction in building costs since this laser design is shorter than the baseline switched design and requires a shorter laser bay.

1.0 Introduction

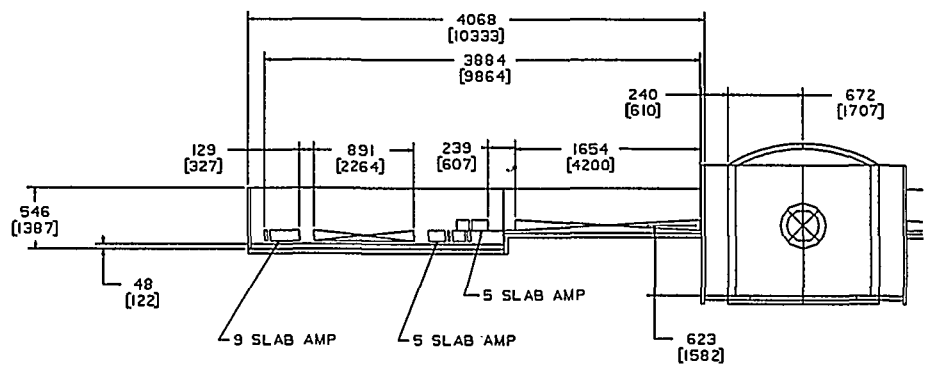
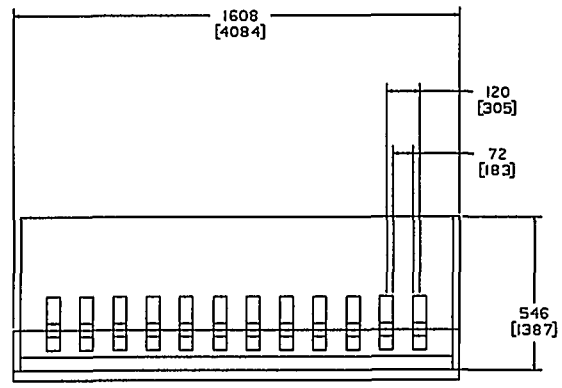
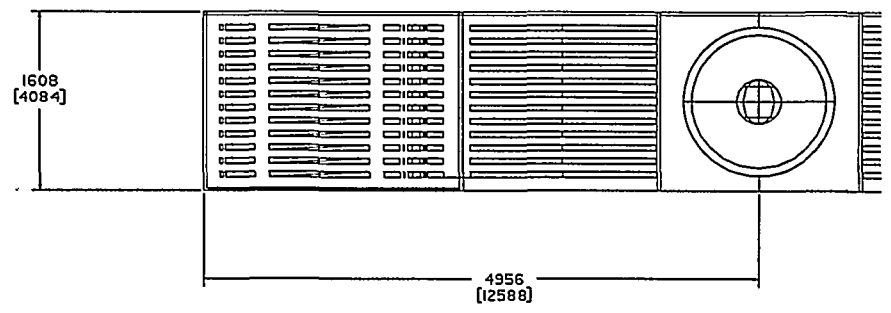
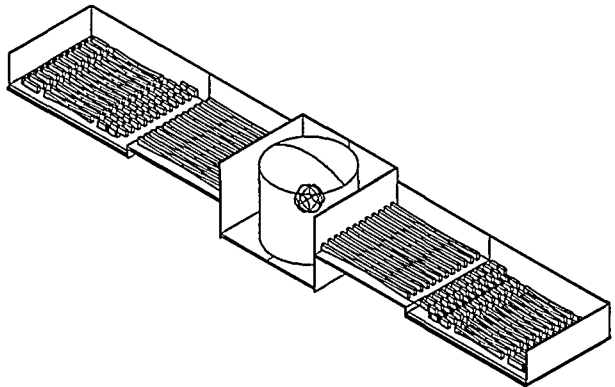
As a result of time limitations during the initial bundle review effort, the bundle review committee expressed concerns about the conclusions reached in the preliminary bundle review report. We performed additional effort on bundle review issues prior to the writing of this report. This effort included:

- Developed an improved 4x2 bundle to reduce its costs
- Performed final beam transport studies for the in-line and alternate building configurations
- Discussed the need for aisles between bundles due to maintenance and operational concerns
- Considered the effect of the U-turn laser architecture on building size
- Performed an analysis of cost differences between the baseline 4x12 bundle and alternate bundle configurations

We then developed new recommendations about bundle size, which are included in Section 7.

2.0 Improved 4x2 Option

We developed an alternate 4x2 bundle concept to the one presented in the preliminary report in an attempt to reduce the 4x2 cost by simplifying the structures in the laser bay and switchyard. The improved concept has a single concrete floor on grade similar to the baseline laser bay, but with the laser supported above the floor by a short steel framework. We assumed that the space between the framework and the slab would be used for utilities and HVAC return. Power conditioning cables would be placed in trenches running across the laser bay that are only located underneath the amplifier sections. A sketch of this concept is shown in Figure 2-1 for the in-line building configuration. For the U-shaped building, we made the switchyard width the same width as the laser bay and kept the same facility support area within the building core. This is consistent with the other bundle designs for the U-shaped building. The cost estimates of several 4x2 configurations were developed in the bundle costing effort discussed in Section 6. Cost estimates were made for the improved 4x2 concept as well as for other 4x2 concepts similar to the 4x12 baseline in the type of structural support. Details of this cost estimating are included in Section 6.



-3-

SAM RODRIGUEZ, 8/15/95
 134FT X 337FT = 45,158 SQ. FT
 FILE: I.SOL.NIF.AMP4X2.I2ARMS-ILEVEL

Figure 2-1 Improved version of the 4x2 bundle in an in-line building configuration. The laser is supported on a short steel framework that covers each laser bay.

3.0 Final Beam Transport Studies

We developed 3-D CAD layouts for several bundle configurations to verify the beam transport path from the spatial filter lens exit to chamber focus lens. The beams were modeled as pipes of square cross section equal to an array of 2x2 individual laser beams. The actual beam layout from the final turning mirror to the focus lens was not modeled (individual beams are slightly diverging with respect to one another) and could increase beam path lengths slightly. We considered several configurations that looked promising:

- **4x2 in-line:** This concept was developed during the preliminary report effort to verify that the in-line building is smaller than the U-shaped building. This concept is shown in Figure 3-1.
- **4x4 in-line building:** This configuration is essentially the same as the 4x2 in-line concept, but using 4x4 bundles instead (or two 4x2 bundles placed together). This concept is shown in Figure 3-2. We also verified that beams could be transported to a second target chamber through the switchyard space, which is shown in Figure 3-3.
- **4x4 in-line bi-level:** This concept was developed based on the assumption that placing the bundles on two floors at the upper and lower mirror plane elevations would reduce final beam transport length. That is, the length of the vertical legs in the switchyard could be reduced. This concept is shown in Figure 3-4.
- **4x4 staggered U-shaped building:** We assumed that the final beam path length for the U-shaped building could be reduced by staggering the location of the final transport spatial filter lens into the switchyard area. Although we only developed a beam layout for the 4x4 bundle, other bundles (particularly 2-wide) could benefit from this configuration as well. One of the stagger concepts that we studied is shown in Figure 3-5.

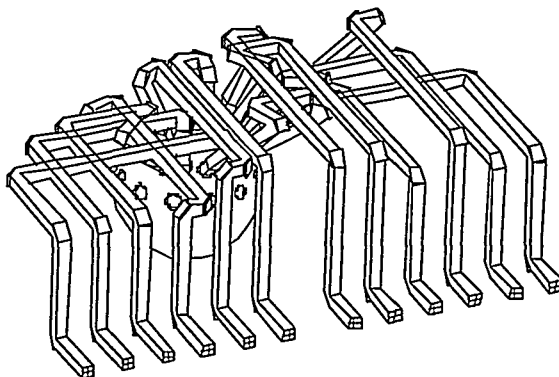


Figure 3-1. Isometric view of the final beam transport from the transport spatial filter lens to the target chamber for the in-line 4x2 bundle configuration. Only the beams in the upper half of a 4x2 bundle are shown, transported in 2x2 groups.

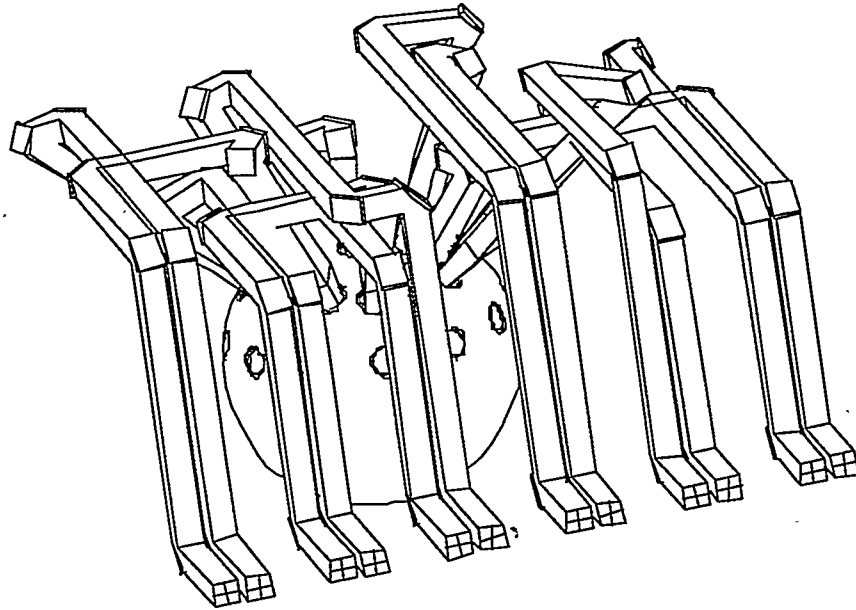


Figure 3-2. Isometric view of the final beam transport from the transport spatial filter lens to the target chamber for the in-line 4x4 bundle configuration. Only the beams in the upper half of a 4x4 bundle are shown, transported in 2x2 groups.

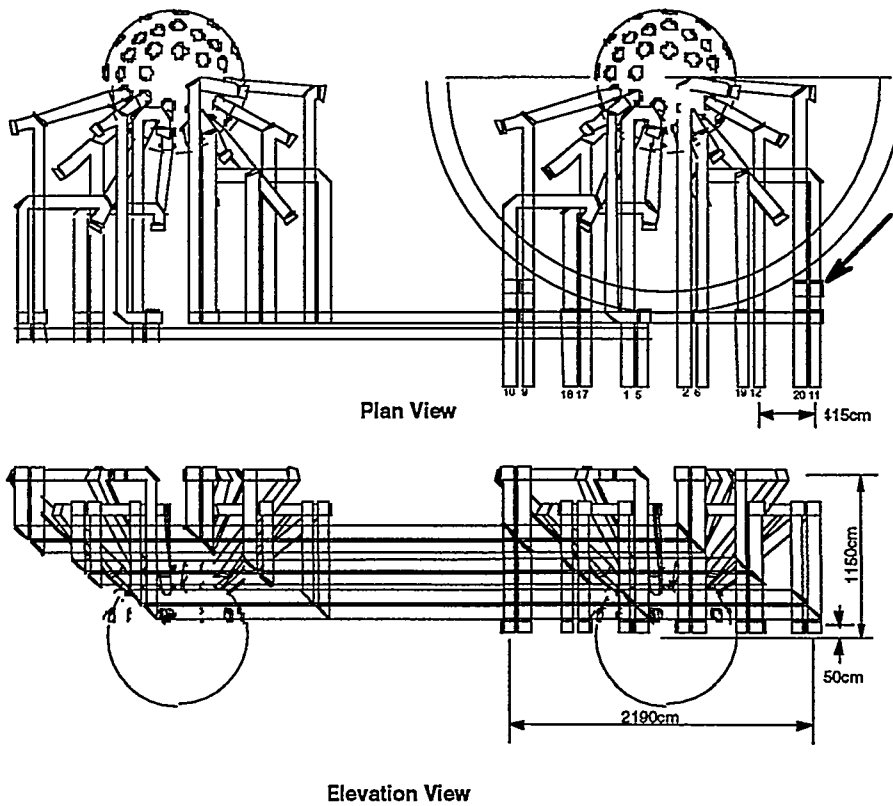


Figure 3-3. View of the final beam transport for the 4x4 bundle in an in-line building, both to the first target chamber and to a second chamber. The actual position of the second chamber would be farther to the left in the figure with the addition of another transport spatial filter.

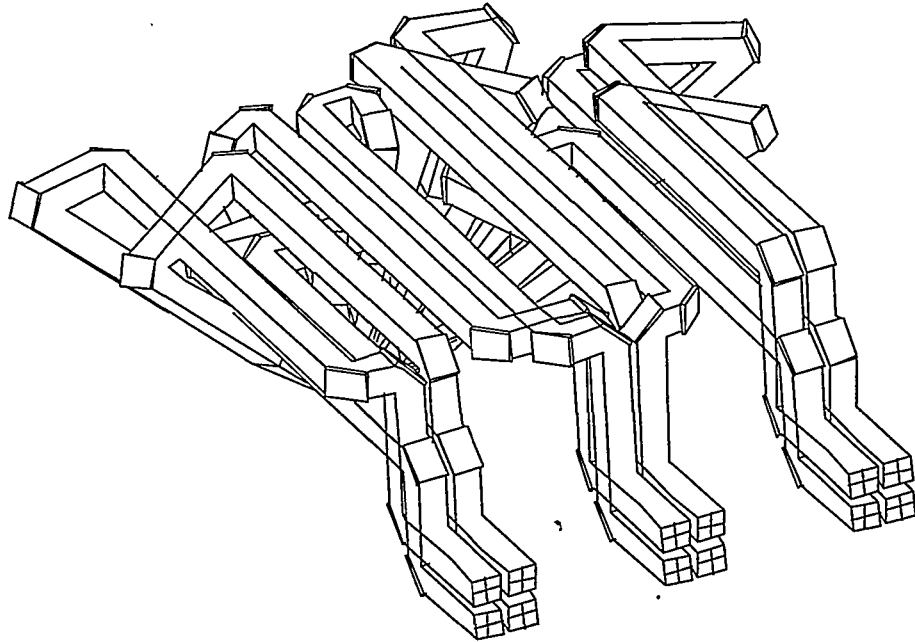


Figure 3-4. Isometric view of the final beam transport from the transport spatial filter lens to the target chamber (not shown) for the in-line bi-level 4x4 bundle configuration. Only the beams in the upper level are shown, transported in 2x2 groups.

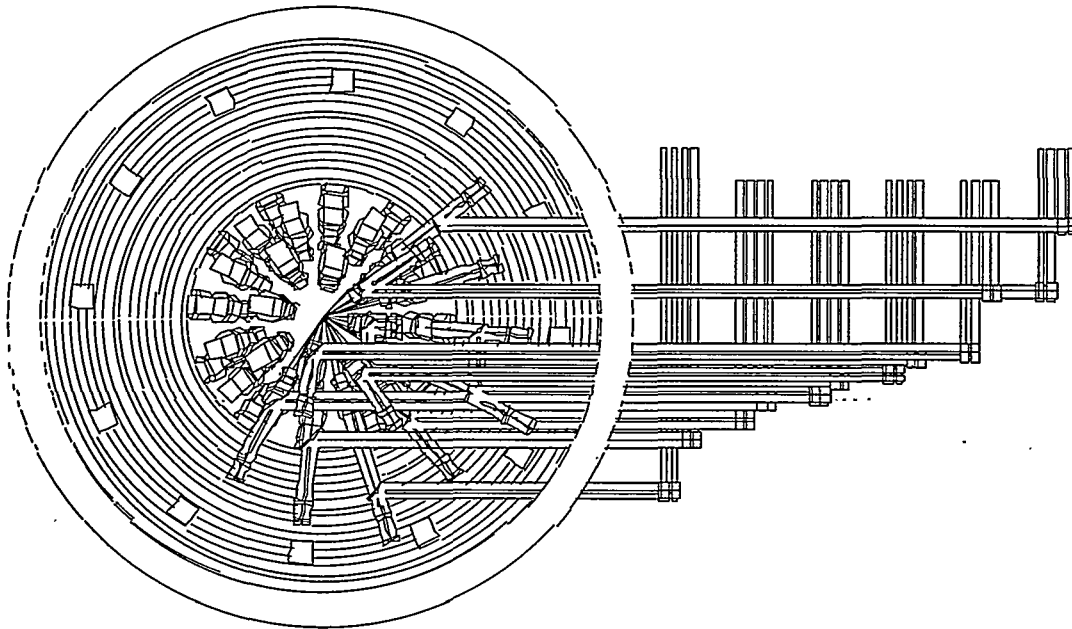


Figure 3-5. Plan view of one of the staggered beam layouts for the 4x4 bundle in the U-shaped building (several other stagger configurations were studied).

Table 3-1. Summary of beam path configurations.

<u>Bundle</u>	<u>Final Path length</u>	<u>Laser Width</u>
4x2 in-line	41.5 m	34.7 m
4x4 in-line	~ 39 m	22.8 m
4x4 in-line, bi-level	~ 38 m	22.8 m
staggered 4x4, U-shape	~ 59 m	22.8 m
4x12 baseline, U-shape	~ 65 m	17.3 m

The final beam transport length for the different configurations is shown in Table 3-1, along with the width of the laser. Conclusions about the beam path studies follow:

- The in-line building clearly has advantages over the U-shaped building in reducing final beam transport length. The in-line configurations are about 25 meters shorter than the baseline 4x12 U-shape design.
- Matching the width of the laser to the width of the target room appears to have an optimum for the in-line building configuration. A laser bay that is too narrow or too wide has a longer final transport length because the beams have to be routed laterally before entering the target chamber room. This is why the 4x4 bundle has a slightly shorter final transport length than the 4x2.
- Beam transport to a second chamber has been verified using an in-line building (see Figure 3-3). This would require the addition of turning mirrors with in/out translation capability to the vertical leg of the beam tubes in the switchyard, modification of these beam tubes to include beam cross junctions, and some additional support structures. The beams would be directed laterally away from the target diagnostic area through a space not occupied by the target room HVAC system (see Figure 3-6). To add second chamber capability to the baseline design, existing mirror mounts and enclosures would have to be modified to include in/out translation capability, and beam tube modifications would be required. The beams to the second chamber would pass through the target diagnostic support area which would require relocation of that support space.
- The 4x4 bundle configuration in an in-line bi-level building (see Figure 3-2) has longer radial transport in the target area, which offsets the reduction in the vertical sections in the switchyard. The total path length can be reduced by 3.5 m less than the concept shown if the bundle is raised to the same elevation as the lower mirror plane in the target area. Beam switchout to the second chamber would be different for the bi-level than for the single floor configuration and has not been verified. The added expense and stability question of a two-floor laser bay do not

appear to offset the gain of a relatively small reduction in final beam transport length.

- The final beam path length in the U-shaped building is reduced with beam staggering in the switchyard, but not to a significant degree. This path length is limited by the width of the laser bay, regardless of the type of staggering used. This is because the outermost-beam in the laser bay must traverse across the switchyard as well as be routed compatibly with the other beams to the final optics package. It should be noted that the path length in Table 3-1 for the staggered U-shaped 4x4 configuration could be reduced with further analysis. Beam staggering offers a number of beam routing options compared to the standard U-shape or in-line building designs with all bundles ending in a plane. However, it is clear that beam routing across the switchyard width for any staggered U-shape configuration will always be greater than routing beams along the switchyard length for the in-line building design. And, staggering presents additional design challenges since the structural supports are not located in a plane.

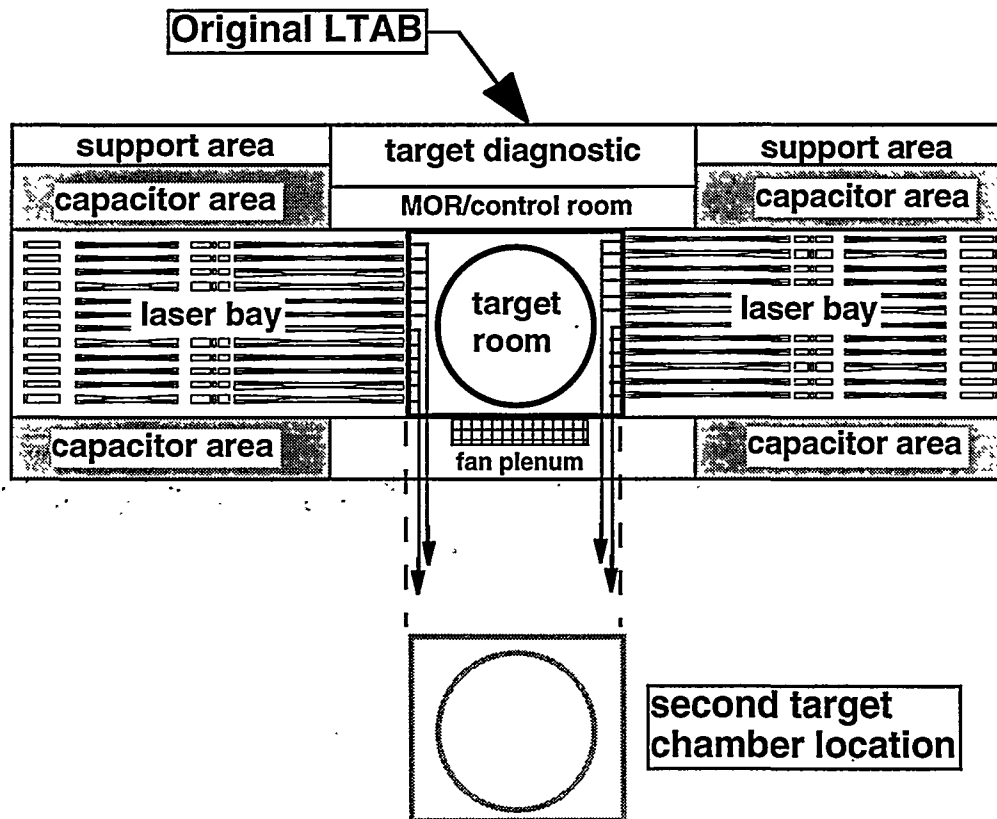


Figure 3-6. Beam routing to the second target chamber can be accommodated with the in-line building design.

4.0 Laser Bay Aisles

We discussed the necessity of aisles in the laser bay to improve access to components along the length of the laser, such as for pinhole plane components, spatial filter lenses, and mirrors (see Figure 4-1). Without aisles, this access could instead be performed from underneath the laser with personnel working off of the floor slab (the same concept proposed for the amplifier), or from above using special catwalks. We discussed the pros and cons of aisles but did not reach any definitive conclusions. Some of the issues we discussed follow:

- Without any aisles, many of the laser system components could be serviced from underneath the laser in a manner similar to the method proposed for the amplifiers in the baseline 4x12 (i.e., in 1x4 arrays). This would require special carts for all components to allow servicing in an acceptable manner in a relatively dirty laser bay (Class 100,000). Access to the L3 mirrors and polarizers would need a different type of access cart due to the stagger and location of these components.
- With aisles, component servicing could be performed laterally in 1x1 or 1x2 modules, which could have advantages over the bottom access concept. All components other than the amplifiers could be serviced this way (including the L3 mirrors and polarizers) in smaller pieces. Side access servicing could be performed with smaller service carts and possibly more quickly. Side access maintenance plans for components would need to be developed during preliminary design in order to verify the structural modifications and the aisle width.
- Mounting the bundles in a close-pack arrangement could prohibit alignment from occurring in an adjacent beam line when servicing another because of vibration transfer. Aisles could provide space for vibration separation, depending on the design of the support structures.
- Aisles provide space for inspection into the laser, which can be performed through windows. Aisles provide space for installing HEPA filters (either temporary or permanent) to protect components from contamination during maintenance operations.

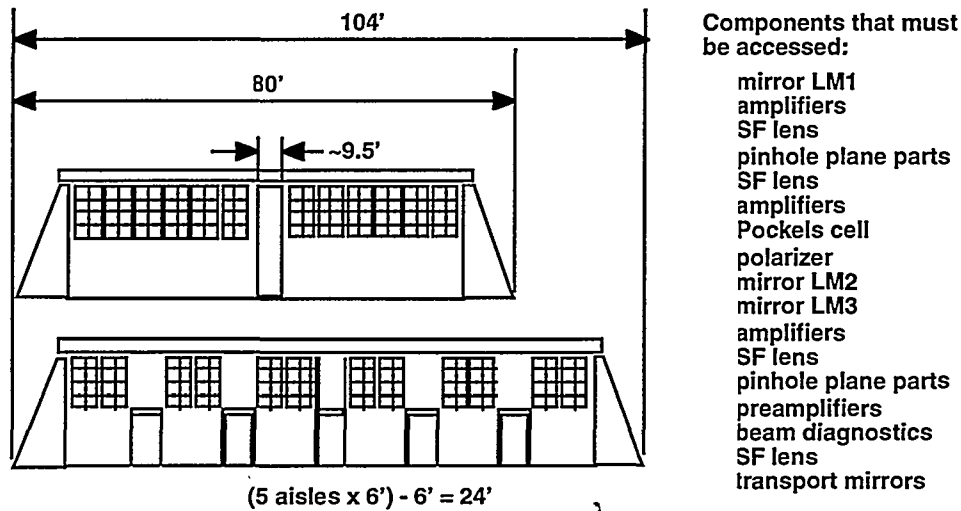


Figure 4-1. Servicing of components along the laser can be done from underneath if there are no aisles between bundles or from the side if aisles are included.

5.0 U-Turn Laser Architecture

The bundle review effort considered variations in bundle size using a switched laser architecture (as demonstrated in the Beamlet laser). As a result of the bundle cost analysis (see Section 6), it became apparent that reducing building cost is an important factor in reducing overall project cost. We considered the effect of using the U-turn laser architecture in an in-line building (a 4x2 bundle was assumed), and compared this to the baseline 4x12 bundle in the U-shaped building and the conventional switched 4x2 in an in-line building. A sketch of this comparison is shown in Figure 5-1.

The U-turn in-line building is about 120 feet longer than the baseline U-shaped building, but slightly narrower on average. However, compared to the switched 4x2 laser architecture, the laser bays are about ~60' shorter for the U-turn 4x2. This results in ~\$10M less building cost at \$602/ft² (unescalated, no contingency) for the U-turn 4x2 than for the switched 4x2 (in-line building).

Should the U-turn architecture prove viable, building costs could be reduced due to the shortening of the laser bays. The difference in hardware cost with the U-turn laser architecture must also be considered to obtain an overall system cost comparison. There are concerns about maintainence and access of the injection hardware for this architecture, particularly with a 4x2 densepack configuration. There would be a fair amount of critical hardware located in a small space that has limited access. Some of the U-turn configurations that we discussed may require aisle space, which limits the configurations that could be utilized (i.e., 4x2 half-aisle or full-aisle options).

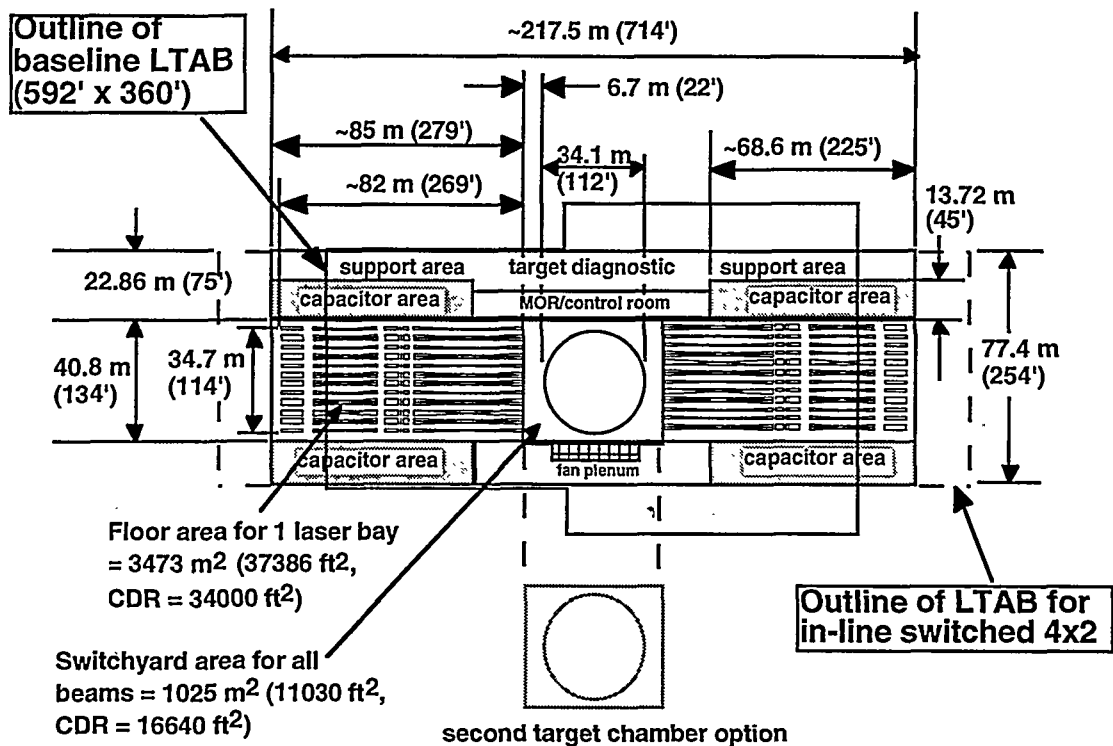


Figure 5-1. Plan view showing an in-line building with 4x2 bundles and U-turn laser architecture, along with the outline of the baseline 4x12 U-shape and 4x2 in-line LTABs having switched laser architecture.

6.0 Bundle Cost Trend Analysis

To better determine the cost of different bundle options, we performed a bundle cost trend analysis using the cost data from the preliminary bundle report. We developed cost factors for the major components and performed a parametric costing analysis of a number of bundle configurations to determine differences in cost relative to the baseline. Details of this are shown in the cost comparison tables at the end of this section. Due to error bars on these cost estimates, the results should only be considered trends and not exact cost differences.

6.1 Bundle Configurations Considered

We considered four building configurations (U-shape, staggered U-shape, in-line, wraparound) and six bundle configurations (4x12, 4x4, 4x2 dense-pack, 4x2 half-aisles, 4x2 full aisles, 2x2). The building configurations are shown in Figure 6-1 and include:

- **Baseline U-shape building:** This is the same design as presented in the CDR.
- **Staggered U-shape building:** This concept has a variable position of the final spatial filter lenses along the length of the laser (i.e., not located in a plane before the switchyard). This staggering of bundles into the

switchyard reduces the final beam transport length and therefore reduces the cost of the transport spatial filter and laser bay.

- **In-line building:** This concept has the laser bays directly opposite one another with the target room in between. This is the same concept presented in the preliminary bundle report.
- **Wraparound in-line building:** This concept has the bundles terminating in a staggered arrangement a constant distance from the target chamber room wall.

The bundle options are shown in Figure 6-2 and include:

- **4x12:** This is the baseline design presented in CDR.
- **4x4:** This is the same design discussed in the preliminary bundle report.
- **4x2 full aisles:** This is the improved 4x2 concept discussed earlier in this report.
- **4x2 dense-pack:** This configuration assumes that 4x2 modules are arranged in a 4x12 configuration, where they are positioned next to one another without any aisles.
- **4x2 half-aisles:** This concept assumes there are aisles between every other 4x2 bundle, which essentially creates a 4x4 bundle from two 4x2 bundles.
- **2x2:** The same design discussed in the preliminary bundle report.

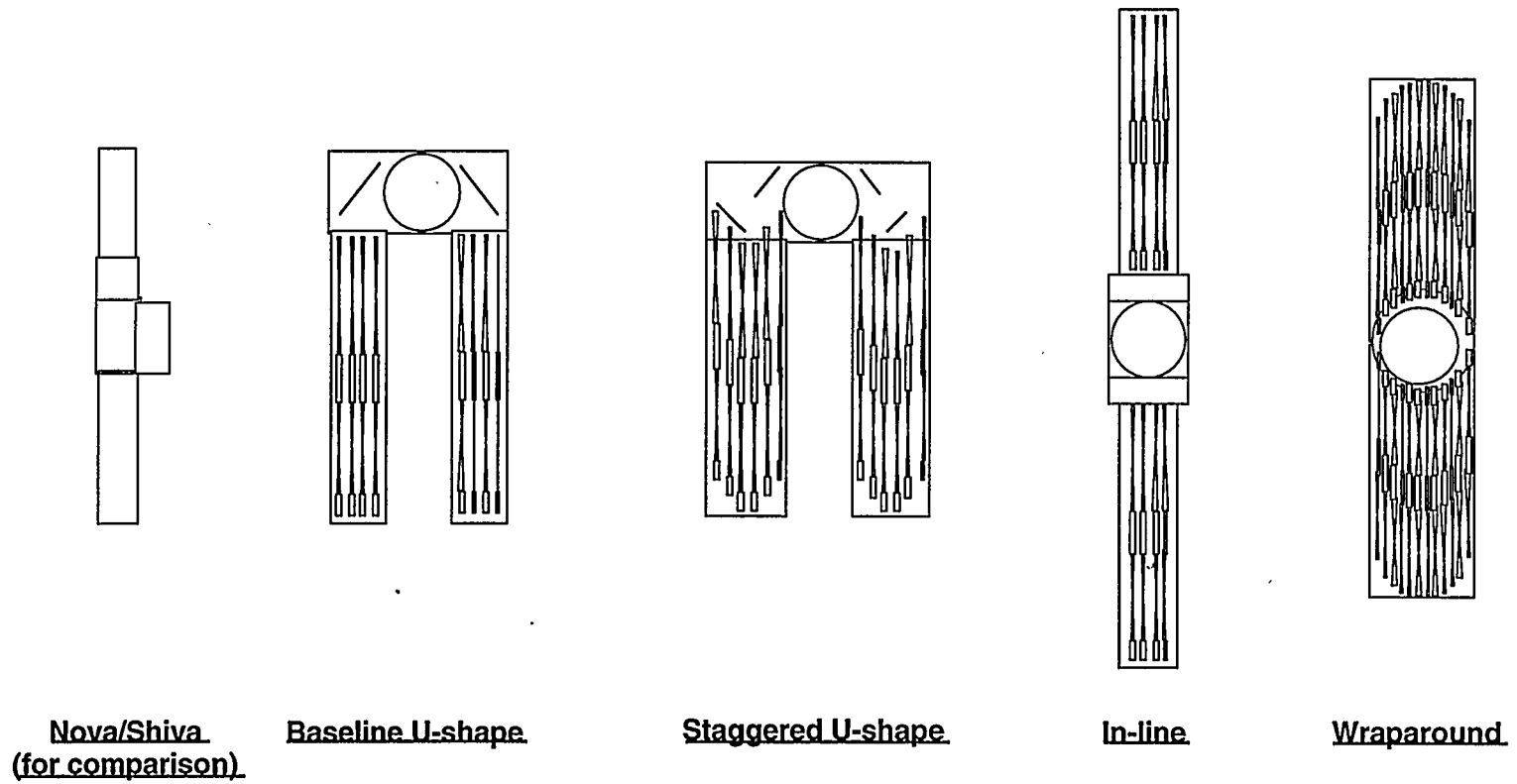


Figure 6-1 Laser structure cost scaling factors vary depending on the type of structure being considered

6.2 Bundle Cost Trend Assumptions

We assumed that some of the cost differences between a given bundle size and the baseline are fixed and do not vary with building configuration or bundle packing. These fixed differences are due to the following laser components:

- pulse generation
- amplifier
- cavity mirror mounts
- transport mirror mounts
- Pockels cell
- polarizer mounts
- interstage hardware
- power conditioning
- beam control

Power conditioning costs are assumed to vary only with bundle size and not with width of the laser bay (i.e., we ignored changes in cable length from capacitor bank to amplifiers). We ignored the effect of differences in beam tube length from spatial filter exit to final optics (transport spatial filter length was accounted for). The number of transport mirrors was assumed constant for a given bundle size.

We assumed that other costs are variable and depend upon differences between the baseline and an alternate bundle. We developed cost scaling factors for several components, which is shown in Figure 6-3. These include the laser bay and switchyard floor area, the laser bay and switchyard structural supports, and the transport spatial filter. The cost of laser bay structures is dependent on the type of structure, which varies with bundle configuration. The different structural options considered along with the costing algorithms are shown in Figure 6-2, and the associated cost variables are listed in Table 6-1.

<u>Laser structure cost variable</u>	<u>Cost Variable</u>
beam cost	\$2707/ft
scaffolding cost	\$32.36/ft ²
plate cost	\$33.28/ft ²
concrete cost	\$599/ft ³
two floor cost	\$69/ft ²
grating cost	\$25.38/ft ²

Cost differences of certain parts of the NIF laser system were ignored, including:

- final optics
- laser auxiliary systems
- target area components
- controls
- optics

These components were assumed to cost the same for any bundle configuration (or assumed to be negligible within the accuracy of this analysis).

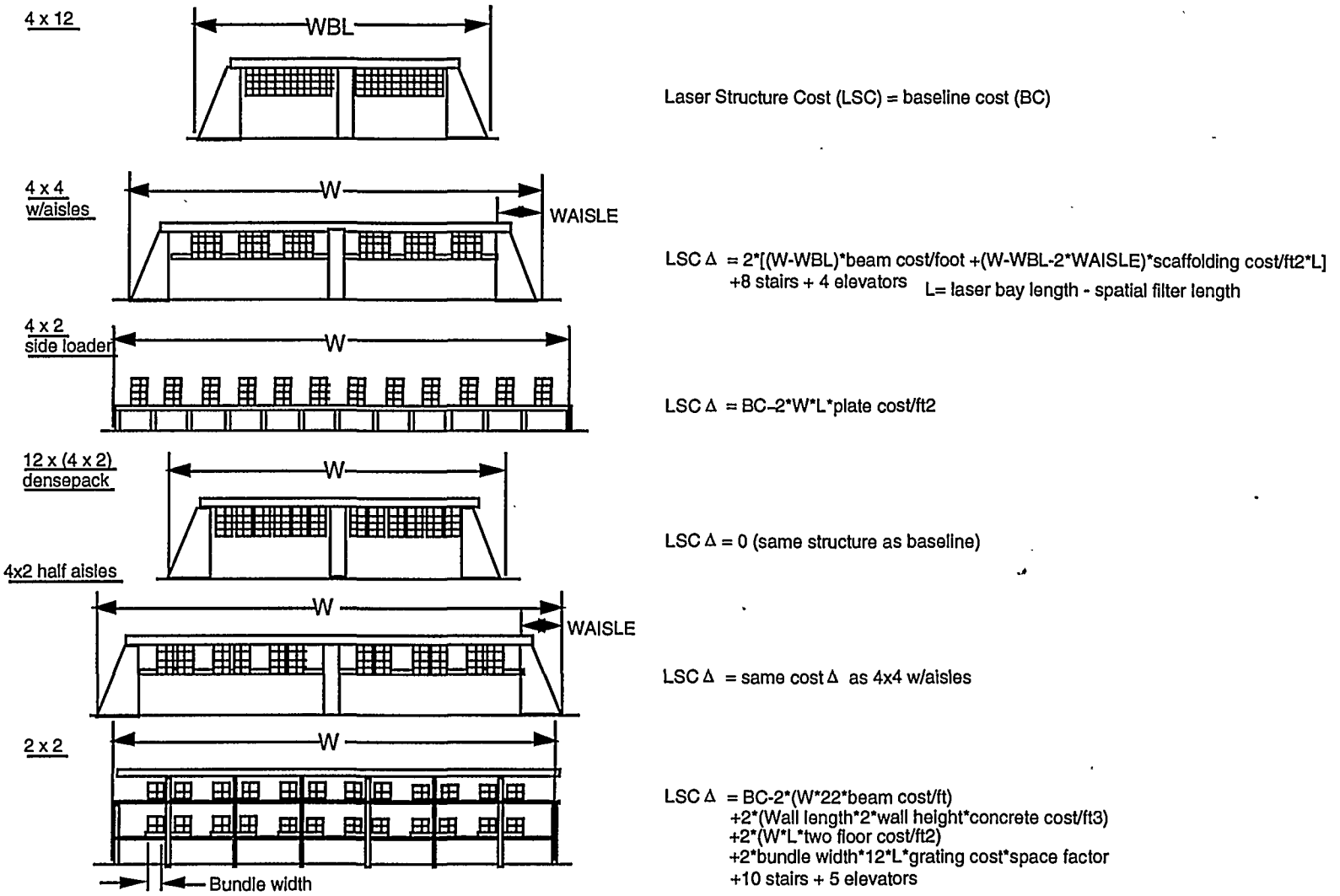


Figure 6-2 Laser bundle options considered. The laser structure cost scaling factors vary depending on the type of structure being considered.

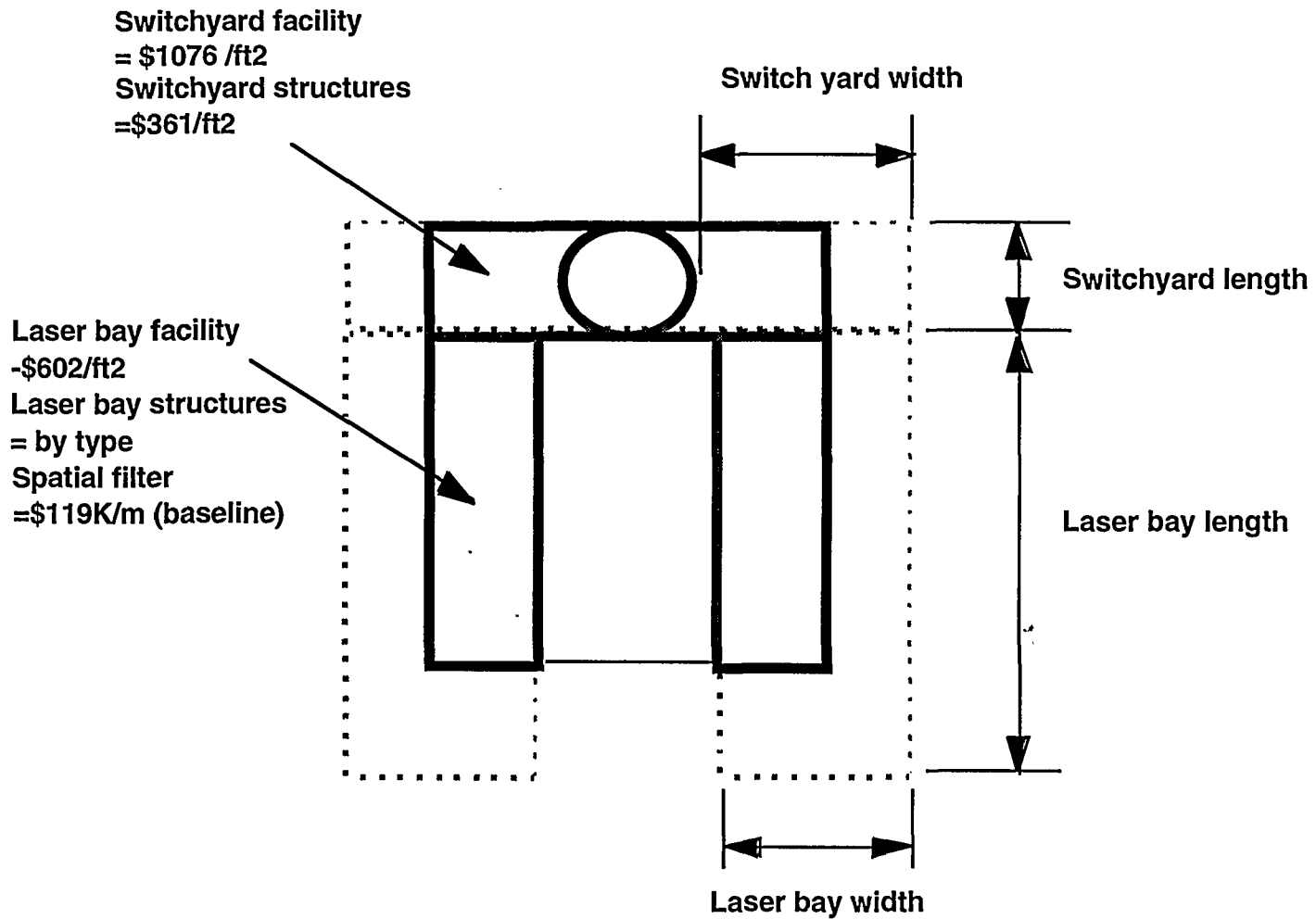


Figure 6-3 The variable costs of the bundle options are scaled with a few simple parameters

6.3 Summary Cost Tables

A comparison of cost trends for the U-shaped building is shown in Table 6-2 for the six different bundle configurations. For three of these configurations, the estimates of the cost deltas relative to the baseline 4x12 can be compared directly to cost deltas found in the preliminary bundle review report:

<u>Bundle Configuration</u>	<u>Cost Delta From Preliminary Report</u>	<u>Cost Delta Using Cost Scaling</u>	<u>Cost Difference Between Preliminary and Final Reports</u>
4x4	\$21.9M	\$28.6M	\$6.7M
4x2	\$55.7M	\$64.9M	\$9.2M
2x2	\$77.7M	\$82.5M	\$4.8M

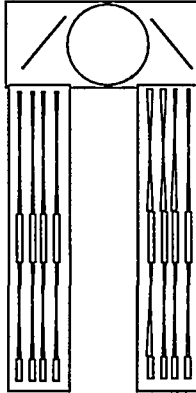
The reasons for these differences are attributed to different assumptions used in the two costing methods. For the 4x4 bundle configuration, the cost delta using the cost scaling method is \$6.7M more than the cost delta in the preliminary report. This is primarily caused by two effects. First, the cost of the U-shaped building in the preliminary report was assumed to be the same as the cost of the building for the 240-beam laser developed during the CDR. Using the cost scaling method, the cost of the building is assumed proportional to floor area based on an average cost per square foot for the laser bays and switchyards. Secondly, the 240-beam building does not have a longer laser bay than the 192-beam building, which would be required to accommodate a longer transport spatial filter that would result from the beams traversing a wider switchyard en route to the target area (the 240-beam laser bay is 24 feet wider than for the 192-beam case). The cost scaling method accounts for both of these effects, which makes the transport spatial filter cost estimate greater (~\$1.5M more) as well as the laser bay (~\$6M more).

The 4x2 laser in this report is an improved version of the 4x2 presented in the preliminary report, and was developed with the intent of reducing its costs. However, the cost delta increased by \$9.2M for several reasons. In the preliminary report, the switchyard building width was made 18 feet less than the width of the laser bay due to an assumption about beam routing. During the cost scaling effort, doubts were raised about the viability of this type of beam routing. We decided to maintain the width of the laser bay into the switchyard for the improved 4x2 bundle, which increased the switchyard building costs. We also revised other assumptions about building costs (such as maintaining the size of the central support area, which was 36 feet narrower in the preliminary report). Cost of modifying the floor slab to include trenches for the power conditioning cables was ignored. The total building cost using average square foot costs increased from ~\$34M above the baseline in the preliminary report to ~\$49M more using cost scaling, which is a \$15M increment. A different method was used to estimate the spatial filter cost which resulted in a ~\$2.5M increment, although the spatial filter length remained the same as in the preliminary report. The cost estimate of structural supports reduced (\$8.5M less) due to the design of

the simple steel framework assumed for the improved 4x2 bundle. Thus, the \$9.2M increment for the improved 4x2 using cost-scaling is justified ($15 + 2.5 - 8.5 = 9$).

The cost delta for the 2x2 bundle in the U-shaped building is slightly higher than the estimate for the 2x2 in the preliminary report (~\$5M more). This is primarily due to spatial filter cost increases (~\$2M more) and structural support cost increases (~\$2M more). Both of these estimates are believed to be more accurate than in the preliminary report due to the bottom-up cost method used. The building costs for the 2x2 bundle are almost exactly the same for both cost estimating methods.

The end result is that the cost estimates of the various bundles in a U-shaped building using cost scaling relate well to the estimates in the preliminary report. This gives us confidence that the estimates using cost scaling for the other building configurations are reasonably accurate. Summary tables of costs of the other building configurations are shown in Tables 6-3 to 6-5.



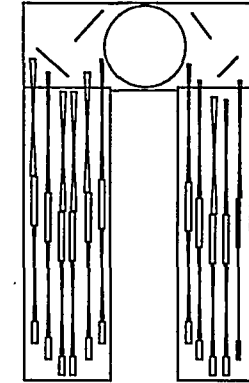
	4x12	4x4	4x2	2x2
Laser bay length - ft	425	449	479	471
Laser bay width - ft	80	104	134	126
Laser bay area (2)-ft ²	68000	93392	128372	118692
Facility fixed cost - K\$	63438	63438	63438	63438
Laser bay unit cost - K\$/ft ²	0.602	0.602	0.602	0.602
Laser structure fixed cost - K\$	1466	1466	1466	1466
Laser bay structure unit cost - K\$/ft ²	0.062	NA	NA	NA
Switchyard length - ft	112	112	112	112
Switchyard width - ft	80	104	134	126
Switchyard area (2) -ft ²	17920	23296	30016	28224
Switchyard unit cost - K\$/ft ²	1.076	1.076	1.076	1.076
Switchyard structure fixed cost - K\$	489	489	489	489
Switchyard structure unit cost - K\$/ft ²	0.361	0.361	0.361	0.361
Spatial filter length - m	65	72	81	79
Spatial filter fixed cost - K\$	22069	19569	19138	19833
Spatial filter unit cost - K\$/m	119	103	113	114

	Project office (fixed)	Laser (fixed)	Facility (fixed)	Spatial filter	Laser bay	Laser bay structures	Switch yard	Switchyard structures	Target area	Total	w/contingency & escalation
4x12	\$26,763	\$344,490	\$63,438	\$29,804	\$40,936	\$5,662	\$19,282	\$6,958	\$43,212	\$580,585	\$634,475
4x4 delta	\$0	\$7,150	\$0	(\$2,819)	\$15,286	\$1,273	\$5,785	-\$1,941	\$0	\$28,615	\$41,128
4x2 delta	\$0	\$14,116	\$0	(\$1,513)	\$36,344	(\$1,410)	\$13,015	\$4,367	\$0	\$64,919	\$93,308
2x2 delta	\$0	\$29,875	\$0	(\$965)	\$30,517	\$8,253	\$11,087	\$3,720	\$0	\$82,488	\$118,558
4x2 densepack	\$0	\$14,116	\$0	(\$3,321)	\$0	\$0	\$0	\$0	\$0	\$10,795	\$15,516
4x2 half aisles	\$0	\$14,116	\$0	(\$2,530)	\$15,286	\$1,273	\$5,785	\$1,941	\$0	\$35,870	\$51,556

*note that 4x2 and 2x2 costs include a \$2.5 M increase that allows for use of a 1x1 Pockels cell

Table 6-2 Bundle cost trends for the U-shaped building configuration

	4x12	4x4	4x2	2x2
Laser bay length - ft	425	406	436	428
Laser bay width - ft	80	104	134	126
Laser bay area (2)-ft ²	68000	84523	116944	107947
Facility fixed cost - K\$	63438	63438	63438	63438
Laser bay unit cost -K\$/ft ²	0.602	0.602	0.602	0.602
Laser structure fixed cost - K\$	1466	1466	1466	1466
Laser bay structure unit cost -K\$/ft ²	0.062	NA	NA	NA
Switchyard length - ft	112	112	112	112
Switchyard width - ft	80	104	134	126
Switchyard area (2) -ft ²	17920	23296	30016	28224
Switchyard unit cost - K\$/ft ²	1.076	1.076	1.076	1.076
Switchyard structure fixed cost - K\$	489	489	489	489
Switchyard structure unit cost - K\$/ft ²	0.361	0.361	0.361	0.361
Spatial filter length - m	65	59	68	66
Spatial filter fixed cost - K\$	22069	19569	19138	19833
Spatial filter unit cost - K\$/m	119	103	113	114



	Project office (fixed)	Laser (fixed)	Facility (fixed)	Spatial filter	Laser bay	Laser bay structures	Switch yard	Switchyard structures	Target area	Total	w/contingency & escalation
4x12	\$26,783	\$344,490	\$63,438	\$29,804	\$40,936	\$5,682	\$19,282	\$6,958	\$43,212	NA	NA
4x4 delta	\$0	\$7,160	\$0	(\$4,159)	\$9,947	\$1,262	\$5,785	\$1,941	\$0	\$21,926	\$31,514
4x2 delta	\$0	\$14,116	\$0	(\$2,982)	\$29,465	(\$1,791)	\$13,015	\$4,367	\$0	\$56,190	\$80,762
2x2 delta	\$0	\$29,875	\$0	(\$2,447)	\$24,048	\$8,115	\$11,087	\$3,720	\$0	\$74,398	\$106,932
4x2 densepack	\$0	\$14,116	\$0	(\$4,790)	(\$6,652)	\$0	\$0	\$0	\$0	NA	NA
4x2 half aisles	\$0	\$14,116	\$0	(\$3,999)	\$9,947	\$1,262	\$5,785	-\$1,941	\$0	\$29,051	\$41,755

This option is worth about \$7 M in cost reductions, but preliminary switchyard layouts are unfavorable

Table 6-3 Bundle cost trends for the staggered U-shaped building configuration



	4x12	4x4	4x2	2x2
Laser bay length - ft	343	343	343	343
Laser bay width - ft	80	104	134	126
Laser bay area (2)-ft ²	54880	71344	91924	86436
Facility fixed cost - K\$	63438	63438	63438	63438
Laser bay unit cost -K\$/ft ²	0.602	0.602	0.602	0.602
Laser structure fixed cost - K\$	1466	1466	1466	1466
Laser bay structure unit cost -K\$/ft ²	0.062	NA	NA	NA
Switchyard length - ft	182	182	182	182
Switchyard width - ft	112	112	134	126
Switchyard area (2) -ft ²	10532	10532	14536	13080
Switchyard unit cost - K\$/ft ²	1.076	1.076	1.076	1.076
Switchyard structure fixed cost - K\$	489	489	489	489
Switchyard structure unit cost - K\$/ft ²	0.361	0.361	-0.361	0.361
Spatial filter length - m	40	40	40	40
Spatial filter fixed cost - K\$	22069	19569	19138	19833
Spatial filter unit cost - K\$/m	119	103	113	114

	Project office (fixed)	Laser (fixed)	Facility (fixed)	Spatial filter	Laser bay	Laser bay structures	Switch yard	Switchyard structures	Target area	Total	w/contingency& escalation
4x12 delta	\$0	\$0	\$0	(\$2,975)	(\$7,898)	\$0	(\$7,950)	(\$2,667)	\$0	(\$21,490)	(\$30,887)
4x4 delta	\$0	\$7,150	\$0	(\$6,115)	\$2,013	\$1,273	(\$7,950)	(\$2,667)	\$0	(\$6,296)	(\$9,049)
4x2 delta	\$0	\$14,116	\$0	(\$6,146)	\$14,402	(\$2,623)	(\$3,641)	(\$1,222)	\$0	\$14,866	\$21,396
2x2 delta	\$0	\$29,875	\$0	(\$5,411)	\$11,098	\$7,840	(\$5,208)	(\$1,747)	\$0	\$38,447	\$52,385
4x2 densepack	\$0	\$14,116	\$0	(\$6,146)	(\$7,898)	\$0	(\$7,950)	(\$2,667)	\$0	(\$10,545)	(\$15,156)
4x2 half aisles	\$0	\$14,116	\$0	(\$6,146)	\$2,013	\$1,273	(\$7,950)	(\$2,667)	\$0	\$639	\$919

The in-line building offers significant cost saving potential

Table 6-4 Bundle cost trends for the in-line building configuration



	4x12	4x4	4x2	2x2
Laser bay length - ft	300	300	300	300
Laser bay width - ft	150	150	150	150
Laser bay area (2)-ft2	90000	90000	90000	90000
Facility fixed cost - K\$	63438	63438	63438	63438
Laser bay unit cost -K\$/ft2	0.602	0.602	0.602	0.602
Laser structure fixed cost - K\$	1466	1466	1466	1466
Laser bay structure unit cost -K\$/ft2	0.062	NA	NA	NA
Switchyard length - ft	0	0	0	0
Switchyard width - ft	20	20	20	20
Switchyard area (2) -ft2	8294	8294	8294	8294
Switchyard unit cost - K\$/ft2	1.076	1.076	1.076	1.076
Switchyard structure fixed cost - K\$	489	489	489	489
Switchyard structure unit cost - K\$/ft2	0.181	0.181	0.181	0.181
Spatial filter length - m	35	35	35	35
Spatial filter fixed cost - K\$	22069	19569	19138	19833
Spatial filter unit cost - K\$/m	119	103	113	114

	Project office (fixed)	Laser (fixed)	Facility (fixed)	Spatial filter	Laser bay	Laser bay structures	Switch yard	Switchyard structures	Target area	Total	w/contingency& escalation
4x12	\$26,783	\$344,490	\$63,438	\$29,804	\$40,936	\$5,682	\$19,282	\$6,958	\$43,212	NA	NA
4x4 delta	\$0	\$7,150	\$0	(\$6,630)	\$13,244	\$2,376	(\$10,358)	(\$4,972)	\$0	\$810	\$1,165
4x2 delta	\$0	\$14,116	\$0	(\$6,711)	\$13,244	(\$2,687)	(\$10,358)	(\$4,972)	\$0	\$2,632	\$3,783
2x2 delta	\$0	\$29,875	\$0	(\$5,981)	\$13,244	\$8,762	(\$10,358)	(\$4,972)	\$0	\$30,570	\$43,938
4x2 densepack	\$0	\$14,116	\$0	(\$6,711)	\$13,244	\$0	(\$10,358)	(\$4,972)	\$0	NA	NA
4x2 half aisles	\$0	\$14,116	\$0	(\$6,711)	\$13,244	\$2,376	(\$10,358)	(\$4,972)	\$0	\$7,695	\$11,061

Wraparound also offers cost reduction potential!

*costs do not include second story structure which is required to “not preclude” a second target chamber

Table 6-5 Bundle cost trends for the wraparound in-line building configuration

6.4 Summary Information

A summary of the bundle comparison cost trends are shown in Table 6-6 along with other information from the preliminary bundle review report. All of the costs of the bundle options in the U-shape building are high (>\$28M above baseline) except for the 4x2 dense-pack (+\$11M). Costs of the staggered U-shape building options are reduced over the standard U-shape building options, but not to a significant degree. The in-line building configurations offer a number of 4x4 and 4x2 bundle options that are similar in cost to the baseline (\$11M less to \$15M additional). The staggered in-line wraparound building offers some additional savings, but the difficulty of adding a second chamber makes it an undesirable option.

A cost trend sensitivity due to variations in assumed average building costs (laser bay and switchyard costs per square foot) is shown in Appendix A for the 4x2 bundle. The total bundle cost delta is fairly sensitive to the average building costs when the building size is much larger than the baseline. This is the case for the 4x2 bundle in the U-shaped building where the floor area is ~75% larger than the baseline. For this case a change of $\pm\$100/\text{ft}^2$ in laser bay cost results in a $\pm\$10\text{M}$ change in the total bundle cost delta. The next smaller case considered is the 4x2 bundle with half-aisles (which has the same floor area as the 4x4 bundle) in the U-shaped building. For this case the floor area is about 35% larger than the baseline building, and a change of $\pm\$100/\text{ft}^2$ in laser bay cost results in a $\pm\$2.5\text{M}$ change in the total cost delta. All other cases are affected to a lesser degree (including in-line building options).

A description of the advantages of smaller bundles is summarized in Table 6-7. This data was largely developed in the preliminary report and is reproduced here to help justify final recommendations.

Average ranking data from the preliminary report is shown in Figure 6-4, which is a summary of the committee's evaluation of the different bundle sizes. It can be seen that smaller bundles have a perceived advantage over the baseline 4x12. There is not a significant difference between the 4x2 and 2x2 bundles.

An estimate of the delivered laser energy with bundle downtime is shown in Appendix B, where downtime results from any reason that causes a bundle to become inactive. Smaller bundles have a much greater average energy delivered on target than larger bundles when the availability is less than 99%. At high availability (99.99%), the effect of bundle size is not significant. It is likely that NIF system availability will always be less than 99%, based on experience from Nova.

In reaching a recommendation about bundle size, it became apparent that once a sufficiently small bundle size is picked, options become available about servicing components. For example, amplifiers in the 4x12 baseline concept are proposed to be serviced from underneath the laser using specialized carts. This same type of servicing can be done for a 4x2 bundle, but the entire amplifier frame is now

small enough that it can be removed from the laser in one piece if necessary and replaced with a refurbished frame (see Figure 6-5). This is not possible in the baseline 4x12 due to the size of the amplifier frame.

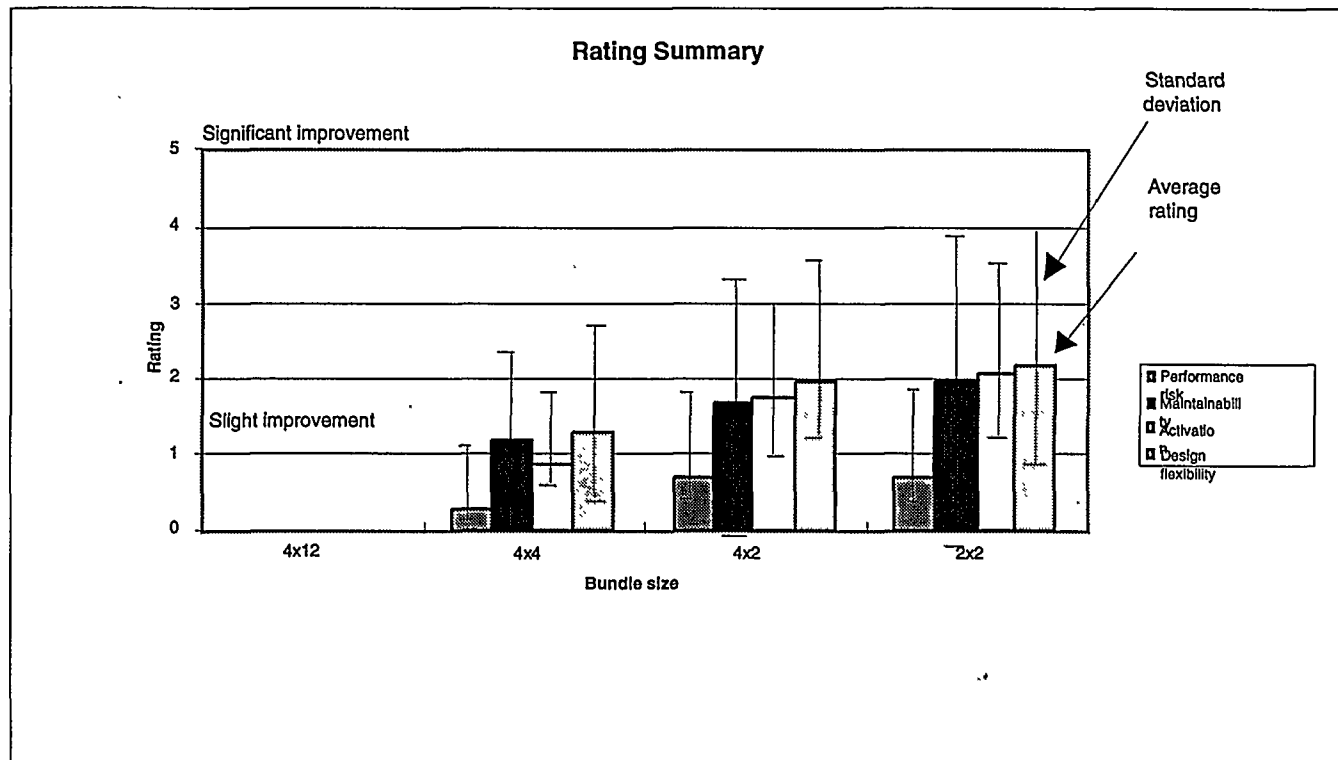
Cost delta - K\$	4x12	4x4	4x2	2x2	4x2 densepack	4x2 half aisles
Baseline U-shape	\$0	\$28,61	\$64,91	\$82,48	\$10,79	\$35,87
Staggered U-shape	NA	\$21,92	\$56,19	\$74,39	5 NA	\$29,05
Unstaggered in-line	(\$21,490)	(\$6,296)	\$14,88	\$35,44	(\$10,545)	1 \$639
Staggered wrap-around	NA	\$810	\$62,63	\$30,57	NA	\$7,69
Relative amplifier efficiency used in cost trend	1	0.92	0.8	0.8	0.8	0.8
Gain uniformity/ distortion (controversial)	good	better	best	best	best	best
Beam balance by symmetry	no	yes	yes	yes	yes	yes
Line replaceable units	no	no	yes	yes	yes	yes
Energy lost per sick bundle	0.25	0.08	0.04	0.02	0.04	0.04
Fraction of shots affected by sick bundle	0.50	0.40	0.40	0.00	0.40	0.40
Beam expansion with wedged lenses	no	yes	yes	yes	no	yes
Initial schedule impact - months	0	2	6	6	No estimate	No estimate
Lens failure cost exposure - delta K\$	0	-819	-1039	-1155	No estimate	No estimate
Flashlamp failure cost exposure -delta K\$	0	-94	-272	-475	No estimate	No estimate
Development cost reduction - delta K\$	0	0	-1800	-2785	No estimate	No estimate
Performance risk rating - ave	0	0.3	0.7	0.7	No estimate	No estimate
Performance risk rating -std dev	0	0.5	0.9	0.9	No estimate	No estimate
Maintainability rating - ave	0	1.2	1.7	2.0	No estimate	No estimate
Maintainability rating - std dev	0	0.9	1.4	1.8	No estimate	No estimate
Activation rating - ave	0	0.9	1.8	2.1	No estimate	No estimate
Activation rating - std dev	0	0.7	1.1	1.3	No estimate	No estimate
Design flexibility rating - ave	0	1.3	2.0	2.2	No estimate	No estimate
Design flexibility rating - std dev	0	1.4	1.4	1.7	No estimate	No estimate
Spatial filter length - m						
Baseline U-shape	65	72	81	79	65	72
Staggered U-shape	NA	59	68	66	NA	59
Unstaggered in-line	40	40	40	40	40	40
Staggered wrap-around	NA	35	35	35	NA	35
Laser bay+switchyard floor area - ft2						
Baseline U-shape	85920	116688	158388	146916	85920	116688
Staggered U-shape	NA	107819	146960	136171	NA	107819
Unstaggered in-line	65412	81876	106460	99516	65412	81876
Staggered wrap-around	NA	98294	98294	98294	NA	98294

*no escalation or contingency is included in cost trends

Table 6-6 Summary comparison table of bundle cost trends with other information from the preliminary report

- Improved maintainability and availability
 - can operate at 96% (4x2) power with 1 bundle down (75% for baseline)
 - potential side access and visibility to internal components (less reliant on diagnostic development)
 - out-of-vacuum component potential (rapid hardware replacement)
- Improved activation scheduling flexibility
 - more independent activities
 - sooner first-off bundle deployment
 - fully deployed bundle with 4% (4x2) of total hardware
- Provides options to in-situ cleaning (line replaceable units)
 - amplifier frame assembly units (for 4x2 and 2x2)
 - optic mounts and support structures
 - more off-line pre-assembly
- Symmetric beam deposition at reduced power
 - increased shot rate at 50% power
- Reduced cost exposure to catastrophic failure or error
- Beam expansion with wedged spatial filter lenses (at increased filamentation risk)
 - other methods may be possible
- Laser hardware stagger to reduce optical path length differences
- Improved gain uniformity control (needs analytical and experimental confirmation)
- Beam balance by symmetry (beam balance can also be controlled with carefully designed flashlamp and reflectors)
- Greater likelihood of synergism with LMJ

Table 6-7 A summary of the advantages of smaller bundles (taken from the preliminary report)

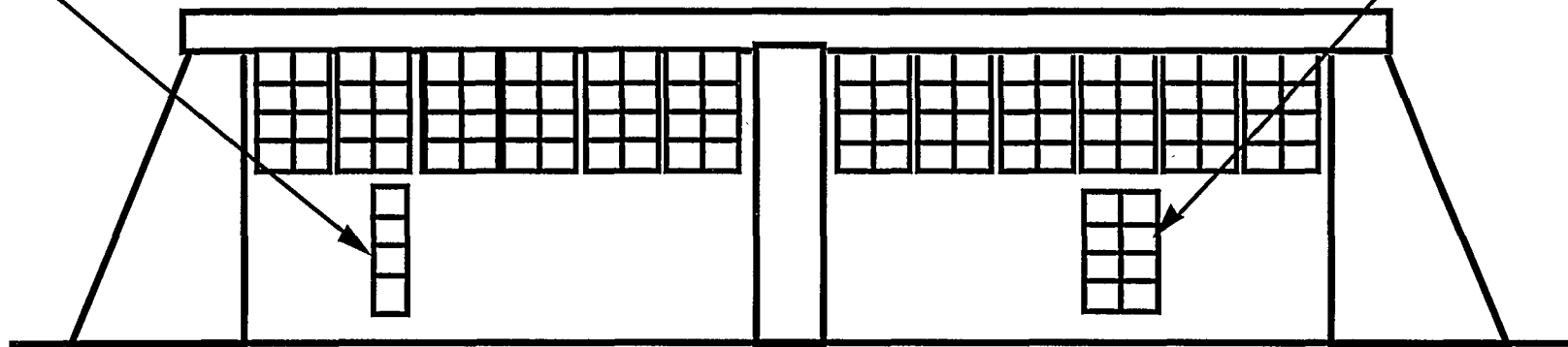


Smaller bundles consistently ranked above larger bundle sizes

Figure 6-4 Bundle ranking data from the preliminary report

4x1x1 slab cassette
being removed for maintenance

4x2xn(3,4,or 5) Frame
Assembly Unit being
removed for maintenance



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Frame assembly units can be line replaceable units

Figure 6-5 A 4x2 amplifier module can be serviced in-situ as assumed for the baseline 4x12 in the CDR, or it can be removed in one piece entirely

7.0 Final Recommendations

We recommend that the NIF baseline laser bundle size be changed to the 4x2 bundle configuration. It offers many advantages over the baseline 4x12, including improved ease of activation, operation, and maintenance; reduced performance risk; and increased design flexibility. There are several 4x2 bundle configurations that could be constructed at a cost similar to that of the baseline 4x12 and provide different degrees of improvement. We estimate that a dense-pack 4x2 bundle could be constructed in a U-shaped building for about \$11M (unescalated, no contingency) more than the baseline. The same dense-pack 4x2 bundle could be constructed in an in-line building for about \$11M less than the baseline. Another 4x2 bundle arrangement with aisles along every other bundle (half-aisles) could be constructed in an in-line building for about the same cost as the baseline.

Our cost estimates are very dependent on the building cost estimates. Cost estimates of the laser component for the bundle options were developed by personnel familiar with the CDR costs. The building costs were developed by extrapolating average square foot estimates from the CDR building costs. Our confidence in the building cost estimates is less than for the laser components. The in-line building is also more of a departure from the baseline building design in terms of construction. Therefore, the cost estimates of the in-line building are even less certain than for the U-shaped building. We recommend that the building cost estimates (particularly for the in-line building) be verified by an architect/engineer (A/E) firm knowledgeable about building design.

If our cost estimates of the in-line building are accurate and therefore result in a change from the baseline U-shaped building layout, the acceptability of the in-line configuration must be reviewed from an operations viewpoint. We need to review the location of rooms within the facility, movement and flow of equipment during operations, and effects on system components due to the building layout change. Some specific examples include: location of operations rooms (control room, MOR, etc.), transportation of components from one end of the building to the other (corridor requirements), fire safety and egress requirements, and acceptability of target diagnostics in the target chamber room (long flight path issue). Although the in-line building may appear attractive from a cost standpoint, we must verify that it is acceptable with long-term operations in mind.

We recommend that installation, operation, and maintenance of all laser components be reviewed to better determine the necessity of aisles. Aisles offer improvements in the amount of access to components, but also cause an increase in building costs. Long-term system operational effects of a laser configuration without aisles are unknown. The need to develop detailed component maintenance plans early in the design process is vital based on past laser system experience on Nova and Beamlet.

The need for beam expansion must be determined since it affects the type of bundle packing that can be used and the resulting effect on laser bay width. If beam expansion is necessary, aisle space must be made available in the laser bays to accommodate larger beams at the switchyard. The 4x2 bundle with half-aisles is a very attractive option to address beam expansion.

The cost of any 4x2 bundle option can be reduced if the building is made less expensive. The U-turn laser architecture offers a reduction in building costs since this laser design is shorter and requires a shorter laser bay. It is not clear how the cost of laser components would be affected, or system performance. A full-scale analytical comparison to the baseline design followed by experimental verification must be performed to verify acceptability of the U-turn architecture before any recommendations about this design can be made.

Appendix A Sensitivity Analysis of Bundle Cost Delta With Variations in Laser and Switchyard Costs

Appendix A shows a cost trend sensitivity for the 4x2 bundle due to variations in assumed average building costs (laser bay and switchyard costs per square foot). The total bundle cost delta is fairly sensitive to the average building costs when the building size is much larger than the baseline. This is the case for the 4x2 bundle in the U-shaped building where the floor area is ~75% larger than the baseline. For this case, a change of $\pm\$100/\text{ft}^2$ in laser bay cost results in a $\pm\$10\text{M}$ change in the total bundle cost delta. The next smaller case considered is the 4x2 bundle with half-aisles (which has the same floor area as the 4x4 bundle) in the U-shaped building. For this case, the floor area is about 35% larger than the baseline building, and a change of $\pm\$100/\text{ft}^2$ in laser bay cost results in a $\pm\$2.5\text{M}$ change in the total cost delta. All other cases are affected to a lesser degree (including in-line building options).

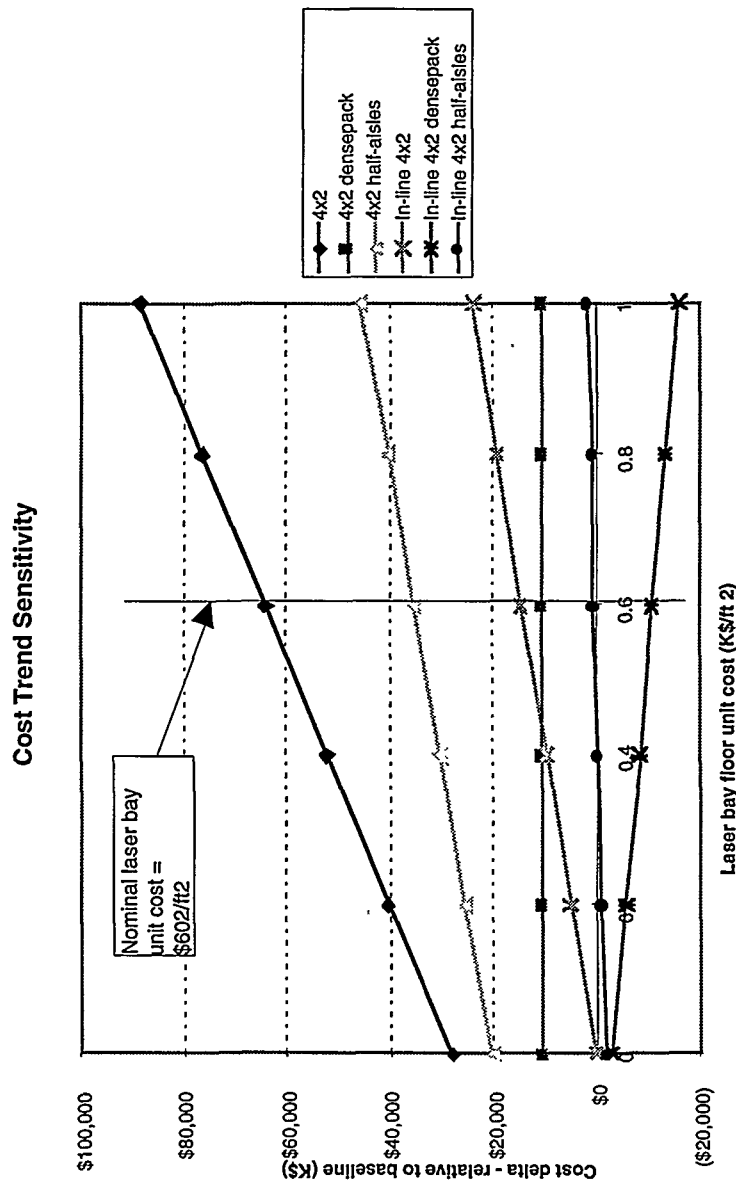


Figure A-1 The sensitivity of cost trends with variations in the average cost of laser bay floor space

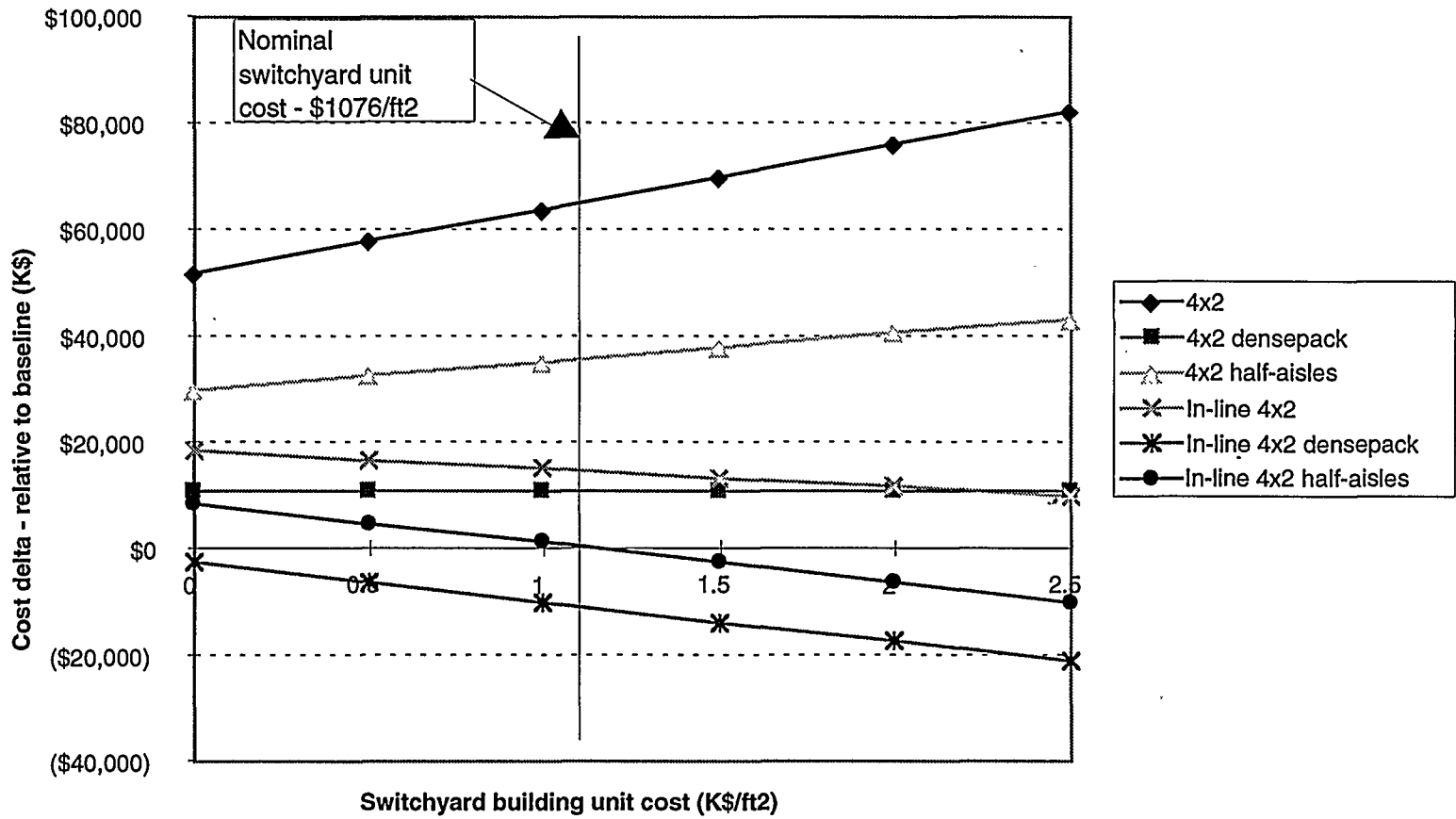


Figure A-2 The sensitivity of cost trends with variations in the average cost of switchyard floor space

Appendix B Availability Comparison with Variation in Bundle Size

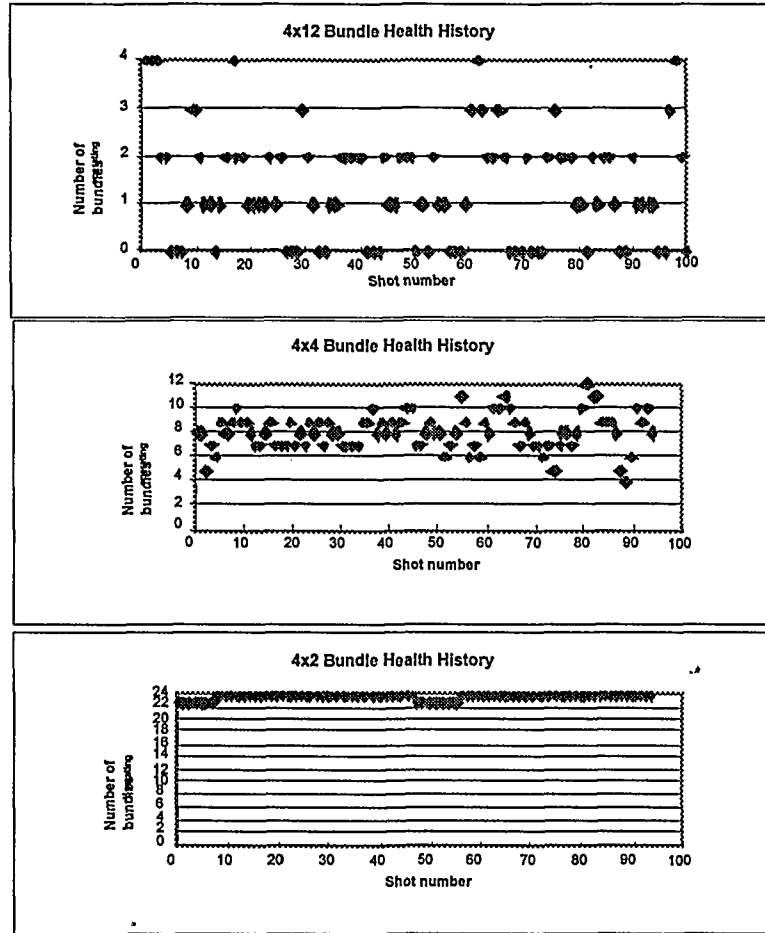
Appendix B shows an estimate of the delivered laser energy with bundle downtime, where downtime results from any reason that causes a bundle to become inactive. Smaller bundles have a much greater average energy delivered on target than larger bundles when the availability is less than 99%. At high availability (99.99%), the effect of bundle size is not significant. It is likely that NIF system availability will always be less than 99%, based on experience from Nova.

Assumptions.

Beamlines are grouped (coupled) into bundles of 48, 16 or 8

Probability that a beamline failure does not cause a beam bundle to become inactive = .9900

Average time a bundle is inactive for unplanned service = 24 hours



Average energy delivered = 0.61 MJ

Average energy delivered = 1.22 MJ

Average energy delivered = 1.79 MJ

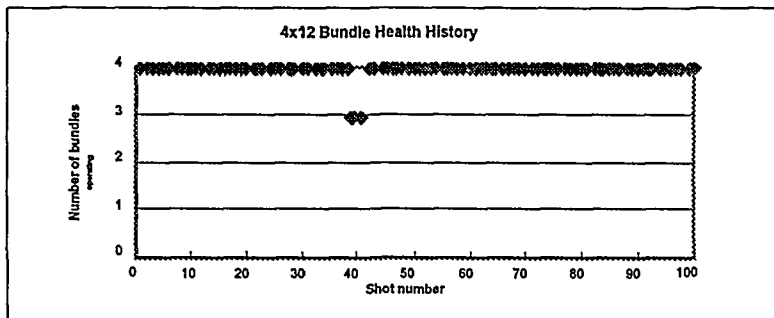
Figure B-1 Smaller bundles are more desirable with low bundle availability (<99%)

Assumptions

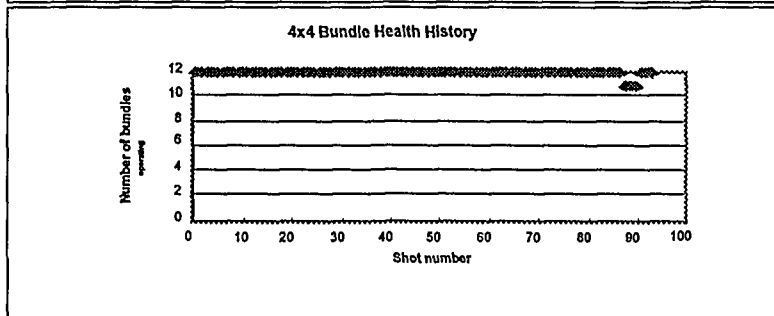
Beamlines are grouped (coupled) into bundles of 48, 16 or 8

Probability that a beamline failure does not cause a beam bundle to become inactive = .9999

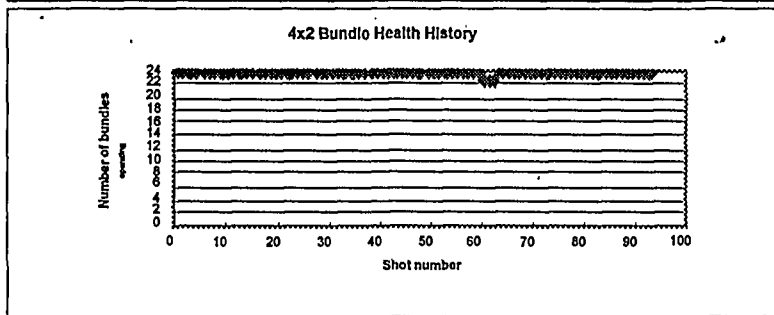
Average time a bundle is inactive for unplanned service = 24 hours



Average energy delivered = 1.79 MJ



Average energy delivered = 1.80 MJ



Average energy delivered = 1.80 MJ

Figure B-2 Bundle size is less important with high bundle availability (>99.99%)

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