RESEARCH DIVISION
INCREMENTAL SHIELDING ASSESSMENT METHODOLOGY

William S. Higgins and Peter Kasper

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Incremental Shielding Assessment Methodology

This document describes in detail the methodology used to perform an "Incremental Shielding Assessment" for the fixed target beamlines. The description covers only those aspects of the shielding which relate to direct protection against beamline accident conditions; in particular, it does not cover such issues as ground water activation, off-site and on-site muon rates, or shielding for experiment halls. The assessment described is a phase I assessment in that it identifies deficiencies in the shielding without addressing the process by which they are corrected.

1. Overview

In the 1990 shielding assessment the amount of passive shielding around each beamline was measured and compared against the "Cossairt Criteria" (memo of 11-DEC-1990 by D. Cossairt, titled "*Generic Shielding Criteria for Compliance with Chapter 6 of the Fermilab Radiation Guide*") which indicated the amount of shielding required for three general categories of beamline; buried beam-pipe, beam-pipe in an enclosure, and beamline elements in an enclosure. This was done by first assessing the shielding overburden directly above the beamline, "Longitudinal Assessment", and then supplementing this with information about the radial distribution of shielding at strategic points along the beamline, "Transverse Assessment". To complete the picture, calculations were performed to determine potential dose rates at the mouths of enclosure labyrinths and penetrations and these rates were compared against the requirements of the Fermilab Radiation Guide.

The calculations from which the Cossairt Criteria were derived assumed a primary beam consisting of 60 pulses per hour of $2\infty10^{13}$ protons at an energy of 1.0 TeV. The calculations performed for the "Labyrinths and Penetrations" assessment were based on the maximum available beam intensity and energy that could be delivered to the beamline at the time of the assessment. These beam conditions have since been superseded through upgrades to the accelerator facility, thereby requiring that the shielding be reassessed using the new limits. Rather than completely redo the assessment (a somewhat labor intensive activity), the Research Division has devised a mechanism for performing an "Incremental Shielding Assessment," in which the results of the 1990 assessment and subsequent modifications are summarized in a form in which they can be easily extrapolated to the latest accelerator performance limits.

The essence of the methodology described here lies in EXCEL spreadsheets which automatically scale the results of previous assessments to the new beam conditions. The new beam conditions are specified in terms of an accelerator cycle time, a primary energy and intensity, a secondary energy and a secondary yield. Note that for simplicity only one secondary energy and yield is provided on the spreadsheets, whereas in reality the secondary beam parameters may vary significantly along a beamline and under different running conditions. This complication is handled by producing a number of assessment reports using different beam conditions, a process which is trivially simple with the new spreadsheets.

Once produced, each spreadsheet is reviewed for accuracy and consistency with previous assessments. Hard copies of the reviewed spreadsheets along with documentation of any changes are recorded and appropriately signed-off in the Research Division Radiation Shielding Documentation.

1.1 Scaling Laws and Conversion Factors

The scaling formulae assume that dose rates scale linearly with intensity, inversely with cycle time, and as energy to the power of 0.8:

$$\dot{D}' = \dot{D} \cdot (I'/I) \cdot (T/T') \cdot (E'/E)^{0.8}$$

where $\dot{D}$ and $\dot{D}'$ are the original and scaled dose rates; I and I' are the original and proposed beam intensities; T and T' are the original and proposed accelerator cycle times; and E and E' are the original and proposed beam energies. Note that this assessment uses the same energy dependence used in the 1990 shielding assessment even though the Fermilab Radiological Control Manual (chapter 13) suggests a linear dependence. Since the scaling is always from 1.0 TeV to lower energies then this choice is the more conservative since it predicts a higher dose rate at lower energies then would be obtained from a linear scaling.

Required shielding thicknesses are scaled by assuming that 2.8 feet of dirt will produce an order of magnitude reduction in dose rate:

$$\Delta t = 2.8 \cdot \mathrm{Log}_{10}\left[(I'/I) \cdot (T/T') \cdot (E'/E)^{0.8}\right]$$

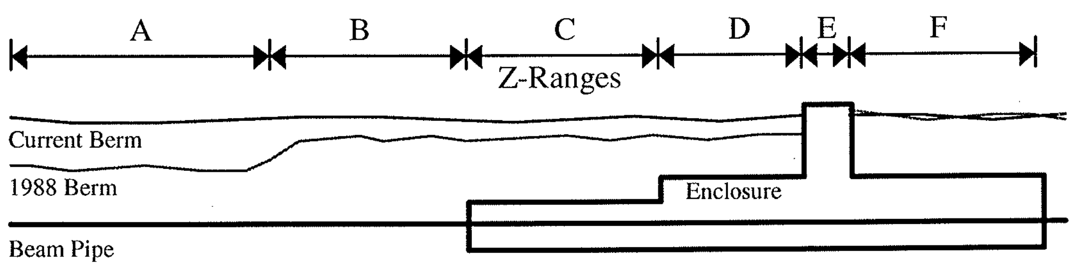
where Δt is the change in the required amount of shielding, measured in equivalent feet of dirt. The factor of 2.8 is derived from the calculated value of 2.6 for concrete (see W.F. Baker, "Research Division Shielding Assessment: Scope, Methodology, and Documentation," 29 July 1991).and correcting for the different densities of concrete (2.4 gm/cm^3) and dirt (2.2 gm/cm^3) as used in the 1990 shielding assessment.

All shielding requirements are measured in equivalent feet of dirt. It is assumed that one foot of concrete is equivalent to 1.1 feet of dirt (this is simply the ratio of densities) and that one foot of iron is equivalent to 2.8 feet of dirt. The number 2.8 is calculated by taking the ratio of absorption lengths for concrete and iron, as given in the Fermilab Radiological Control Manual ($44.6/17.3 = 2.6$) and correcting for the different densities of concrete and dirt.

1.2 Longitudinal

The 1990 shielding assessment utilized berm elevations derived from the 1988 aerial survey data, to produce longitudinal profiles of the berm for each beamline. The enclosures, labyrinths, penetrations, and buried as well as removable shielding were hand drawn onto these profiles to produce a scale drawing of the amount of shielding present. Based on these drawings each beamline was broken up into regions in which the shielding was reasonably homogenous and each region (or Z-range) was assessed against the "Cossairt Criteria". As exceptions were discovered, recommendations were made, and necessary modifications were completed. Where required, optical surveys were then conducted to certify that the correct amount of shielding was added. This optical data was then added to the shielding documentation to adjust the final shielding numbers appropriately.

The Z-ranges are chosen based on many aspects. As an example, if an enclosure contained one equipment hatch, and two differing enclosure ceiling heights, one might separate the enclosure into four Z-ranges (C through F) as shown in the diagram below. Wherever possible long Z-ranges based on geometry are chosen. However at times regions that could constitute a single Z-range are broken into smaller ones based solely on differences present during the 1990 assessment. For example in the diagram below the region upstream of the enclosure is split into two ranges (A and B) because the changes in the berm elevation were significantly different in those regions.

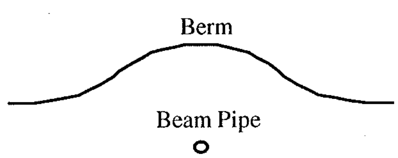


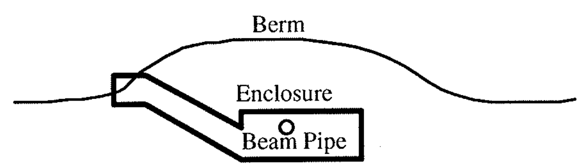
The spreadsheets used in an Incremental Assessment combine the information obtained in previous assessments with current berm survey data to obtain an up to date measure of the existing shielding over the beamlines. The Cossairt Criteria are scaled to current beam parameters and the resulting shielding requirements are compared against the existing shielding. In this way one can quickly locate exceptions for any given beam parameters without having to refer back to drawings.

The 1990 assessment information was used to generate the spreadsheets used in the Incremental Assessments and constitutes the baseline data. The information in the new spreadsheets was checked for accuracy against the 1990 assessment documents and any necessary adjustments were justified and recorded in the Spreadsheet Adjustment Documents described in section 1.5. Changes to the baseline data can also occur as a result of construction work or modifications to the beamlines and are documented in the same way.

1.3 Transverse

The Transverse Assessment involves cross sections of the berm and enclosures at selected locations along the beamline. The idea is to verify radial shielding about the beam centerline. Cross section locations are chosen based on the longitudinal drawings and the need to analyze specific regions. For example, locations may be chosen in order to insure that the berm is correctly centered over the beamline, or that there is sufficient shielding to the sides of a beamline to compensate for the changes in the enclosure geometry. Transverse sections are also used to aid in understanding labyrinths and penetrations and what types of loss scenarios are possible. Examples of typical transverse configurations are shown below. In some cases the enclosure geometry for a single transverse location constitutes several nearby cross sections collapsed onto the same plane. This is done to minimize the number of drawings and is always configured to produce a worst case scenario for the region. For example, in the second illustration the enclosure entrance is treated as a single leg, perpendicular to the beamline, whereas, in reality, it may have been a triple-leg labyrinth or it may have been angled with respect to the beam.





The analysis of the transverse sections is very similar to that of the longitudinal sections and the Incremental Assessment spreadsheets are constructed in an analogous manner. The difference between the Incremental Assessment and the baseline assessment is that the enclosure layouts have been digitized into computer files so that the process of evaluating the shielding can be done by computer rather than by visually inspecting drawings.

The information in the files containing the digitized enclosures along with other data on the spreadsheets has been extracted from the 1990 shielding assessment and subsequent changes are recorded and justified in Spreadsheet Adjustment Documents just as in the Longitudinal Assessments.

1.4 Labyrinths and Penetrations

The technique of measuring the amount of passive shielding between the beam and the outside does not work in the case of enclosure labyrinths and penetrations. Instead the dose rates at the outside entrance to the labyrinth or penetration are calculated using the methodology described in the document titled "*Labyrinths and Penetration Methodology*" by R. Rameika (July 1991). The doses were then compared against the doses allowed for the type of area in question and any exceptions were noted and corrected.

The current assessment uses the dose calculations of previous assessments and scales them according to the latest beam parameters. Thus the calculation need only be repeated if the labyrinth or penetration geometry is altered. The spreadsheet is constructed to look and behave much like the spreadsheets used in the Longitudinal and Transverse assessments.

1.5 Spreadsheet Adjustment Document

Upon completion of the incremental assessment, a Spreadsheet Adjustment Document is prepared for each beamline. It is used to document significant changes made to the spreadsheets. These are changes that affect the spreadsheet's determination of how much shielding is present or required and includes changes to any cells designated as "Review Data" in section 2. The purpose of the Spreadsheet Adjustment Document is to document and explain the rationale used in making changes between the previous and current assessment.

The document is broken into three sections; one for each of the three assessment types. Each section summarizes the changes made to the relevant spreadsheets. The summary for each change should contain a succinct description of the change, a detailed explanation of the reasons and justifications for the change and references to any supporting documentation. For some frequently occurring changes, the justification may be replaced by a justification code indicating the nature of the change. These codes and their explanations are detailed in section 1.5.4 below.

1.5.1 Longitudinal Adjustment Examples

The following examples describe some regularly occurring situations which would require documented changes to the Longitudinal spreadsheets. This is not intended to be a comprehensive list of changes that require documentation but rather a guide as to the level of documentation required.

- The Z-ranges used in the spreadsheets will occasionally need to be adjusted. The reasons may range from changes in the beamline coordinate system as used by the alignment group to changes in the shielding which are not uniform across an existing Z-range. The documentation should specify the old and new Z-ranges, the reason for the change and if relevant, reference drawings which justify those reasons.

- Modifications to the amount of baseline or removable shielding need to be carefully documented and verified. Such changes will generally result from construction projects which change the size or configuration of enclosures. The documentation for such changes should include references to the new as-built construction drawings.

- The addition or removal of radiation fences or detectors will result in a change in the Cossairt classification of the affected area. The adjustment summary should include a description of where the fence or detector was added (or removed), the reasons for the change and references to maps and worksheets indicating that the change had been verified.

1.5.2 Transverse Adjustment Examples

The following examples describe some regularly occurring situations which would require documented changes to the Transverse spreadsheets. This is not intended to be a comprehensive list of changes that require documentation but rather a guide as to the level of documentation required.

- The addition of any stations not listed on the previous spreadsheet will generally require a new cross-section drawing as well as a new entry in the geometry file. The documentation should include the reasons why the new station was required, a reference to the relevant "as-built" drawing and a copy of the drawing produced by the program THICK. The latter should be checked against the "as-built" in order to verify the geometry file.

- In the Incremental Assessment the Z location of the station is used to define the exact location from which the berm profile is measured. It may be necessary to adjust this value in order to avoid a region in which the survey data is unreliable. Such reasons should be documented along with the drawing produced by the program THICK, and a justification demonstrating that the adjustment still results in a valid assessment.

- Any modifications to the geometry file should be supported by references to the relevant "as-built" drawings. The modifications should also be verified by comparing the drawings produced by the program THICK with the "as-built" drawings.

- Changes affecting the Cossairt classification of a station should be documented as in the case of the Longitudinal assessment.

- The transverse spreadsheets are created from the output ot the THICK program. The "Shielding with Air" column contains the value of the shortest path through the shielding. The spreadsheet will indicate this as a failure if the path length is below the acceptable value. It is possible that, once a solution is implemented to improve this shielding, and THICK is run again with a revised model of the new shielding geometry, a new failure will be indicated along a different path. In a sens the new problem was "hidden" by the old problem. In such cases, trial and error may be necessary to find a set of solutions which resolve all shortages.

1.5.3 Labyrinth and Penetration Adjustment Examples

The following examples describe some regularly occurring situations which would require documented changes to the Labyrinths and Penetrations spreadsheets. This is not intended to be a comprehensive list of changes that require documentation but rather a guide as to the level of documentation required.

- The addition of a new labyrinth or penetration should be accompanied by references to construction drawings and the number of the worksheet in which the baseline calculation is performed. All these documents should be incorporated into the overall shielding documentation.

- Changes affecting the Cossairt classification of the area should be documented as in the case of the Longitudinal assessment.

1.5.4 Standard Spreadsheet Adjustments

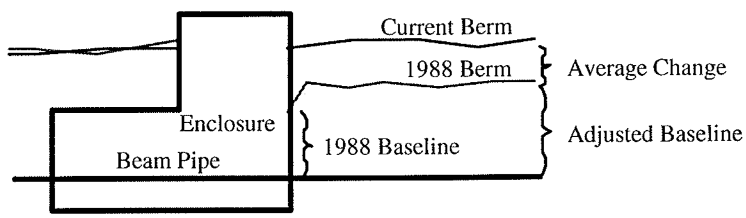
There are some types of changes to the assessment spreadsheets which occur frequently and which have a common reason. Rather than make the Spreadsheet Adjustment Document cumbersome and repetitious, codes have been assigned to these standard adjustments which can be used in lieu of a full description and justification. These codes and their explanations are given below.

Standard Baseline Shielding Adjustments:

- Change code **BSC-STL**: In the 1990 shielding assessment a foot of steel shielding was treated as being equivalent to 3.0 feet of earth. For consistency with the Fermilab Radiological Control Manual this conversion factor has been changed to 2.8 feet of earth per foot of steel and the amount of baseline shielding has been reduced accordingly.

- <u>Change code</u> **<u>BSC-NRG</u>**: In order for the Longitudinal shielding assessment to produce accurate results the actual change in shielding needs to be reasonably well represented by the *average* change in the berm height. In order to ensure that this assumption holds true some of the original Z-ranges have been broken up into smaller regions where the change in the berm is more nearly uniform. This is particularly true near roads and enclosure hatches: dirt may have been added to the berm on either side of the road or hatch but not on the road or hatch itself. Thus it is better to treat the road or hatch as a separate Z-range and fix the shielding change in that range to zero.

- <u>Change code</u> **<u>BSC-AVE</u>**: During the 1990 Longitudinal shielding assessment, a Z-range was evaluated to determine the *minimum* thickness of shielding present. In some cases this may have occurred in a highly localized region such as a hole or on the edge of a steep slope. The methodology for the incremental assessment adds the *average* change in thickness to this minimum which may result in seriously under-estimating the actual amount of shielding. In such cases the baseline shielding will be changed from the 1990 minimum to a more representative value. This situation is illustrated in the diagram below. Note that the adjusted baseline shielding is chosen such that it still represents the weakest point when the average change has been added.



<u>Standard Cossairt Category Changes:</u>

- <u>Change code</u> **<u>CCC-FNC</u>**: A common method of improving the protection in an area of weak shielding is to simply enclose the area with an appropriately posted radiation fence. This will result in a change in the Cossairt classification of the area. The location of the fence will be documented and verified during the phase II and phase III assessments. This documentation should be referenced in the Spreadsheet Adjustment Document.

- <u>Change code</u> **<u>CCC-DET</u>**: The addition of an interlocked radiation detector will reduce the worse case accident condition to a single pulse accident. Areas protected by such devices require less shielding and fall into a different Cossairt Category. Documentation of the type, setting, and location of the detector will be included into the phase II and phase III assessments. This documentation should be referenced in the Spreadsheet Adjustment Document.

1.5.5 Special Calculations and Dose Limits

Dose Limits for Interlocked Detectors

The recent revision of the Fermilab Radiological Control Manual (March 1995, pages 2-25 through 2-31) specifies dose limits in millirem per hour. Where a beamline is protected by an interlocked radiation detector such as a chipmunk or scarecrow, such detectors will be set to trip off the beam well below such limits, and will not be reset without the approval of an RSO. This procedure will ensure that the hourly dose limits are not exceeded.

The lookup table for dose limits in the Labyrinths and Penetrations spreadsheets has been changed to reflect these mrem/hour limits. This will replace the previous values, which assumed ten trips per hour.

Where (accident rates/pulse)*(pulses/hour) are much more than the limit:

A. If more than one pulse would exceed the limit, assume the chipmunk or scarecrow will be in Manual mode, and will trip after one accident pulse. Use the single-pulse dose to calculate the "credit" shielding value.

B. If several pulses will pass the limit, assume the interlocked detector will be in "manual" mode, and will trip off after three pulses. Compare the three-pulse dose to the limit in calculating the "credit."

Assigning Shielding "Credit"

The shielding requirement for a Cossairt cateogry implies a certain dose outside the enclosure. A dose lower than this can be thought of as having more "shielding." The difference between this larger number and the *existing* shielding is the "credit" value that should be entered into the "Old Solutions" column. (If the value in the "Difference" column is inadequate, the credit value also appears in the "Past Solutions" column.)

For example, take the Neutrino Test (NT/NK) beamline, in the longitudinal region from 6469 to 6519. According to calculations in supporting documents accompanying the Shielding Exception Summary, the existing shielding of 6.0 equivalent feet of dirt gives rise to a dose of 22.9 mrem/pulse for the maximum accident intensity, 6×10^{11} particles/pulse, and energy, 200 GeV.

The category of this region is 9A, which permits up to 500 mrem/hour, and requires 7.2 efd shielding for this intensity and energy.

Assuming the detector trip setting is "automatic," then at most the dose can be three trips at 22.9 mrem/pulse before a manual reset is required. This represents a dose of 68.7 mrem; after this the RSO will be called to interevene.

Compare this dose to the upper limit of 500 mrem/hr to find L, the shielding equivalent thickness:

$$\frac{68.7}{500} = 10^{\frac{-L}{2.6}}$$

$$L = -2.6\left(\log \frac{68.7}{500}\right) = 2.24 \text{ efd}$$

So the difference in doeses corresponds to a thickness of 2.24 efd in excess of the required shielding. The requirement is 7.2 feet, so the total equivalent is 9.44 efd.

Comparing this to the existing shielding, 6.0 efd, the shielding credit is:

(9.44 - 6.0) = 3.44 efd

and this figure is entered into the "Old Solutions" column on the longitudinal spreadsheet for this range. (Shielding credit calculations for transverse spreadsheets are done in a similar fashion, where needed.)

Meaning of Negative Required Shielding Thicknesses

The longitudinal and transverse spreadsheets calculate required thicknesses by adding a correction value to the Cossairt standard for 2 x 10^{13} ppp and 1000 GeV. For very low intensities or energies, the result of this calculation may be a negative number. This unphysical value is a consequence of the scaling method used, and is presumed to require a shielding thickness of zero.

1.6 Shielding Exception Summary

To complete the Incremental Assessment a Shielding Exception Summary is generated for each beamline which is intended to serve two purposes: It provides management with information as to what work will be necessary in order to run a particular beamline under a given set beam conditions and it provides the basis for generating Phase II worksheets for those parts of the beamline which are flagged as having insufficient shielding under those beam conditions.

For each exception found in the spreadsheets the Shielding Exception Summary should contain the following information:

- A brief description of the problem with some indication of its severity. For instance if the Longitudinal assessment flags a large Z-range as being a foot short of the required amount of shielding then the Shielding Exception Summary will give some indication as to what fraction of that Z-range is affected.

- A list of possible solutions or a statement that no obvious solution exists. For instance the problem may be readily solved by the addition of a fence, extra dirt, or an interlocked radiation detector. The choice of which solution is appropriate is left to the phase II part of the assessment should management decide to proceed with the shielding upgrade.

Some parts of the beamline may have sufficient shielding only if solutions that were applicable in the past can still be used. These areas are clearly indicated on the spreadsheets and should also be mentioned in the Shielding Exception Summary along with some indication as whether or not the past solutions still apply.

1.7 Relation to Phase II, Phase III, and Review Process

This section describes how the Incremental Shielding Assessment fits in to the overall shielding assessment; including the phase II and phase III assessments and the review process.

- The process begins with the RSO reviewing the current spreadsheets and incorporating the effects of any relevant changes to the beamline. At the end of the review the RSO will produce hard copies of the assessment spreadsheets and the Spreadsheet Adjustment Document for the beamline.

- The proposed beam parameters on the reviewed spreadsheet are adjusted to represent the maximal energy and intensities anticipated for the coming run, and a Shielding Exception Summary is produced. The proposed beam parameters are provided by the responsible beamline physicist.

- The Shielding Exception Summary is submitted to the Research Division Office for review. Using this information, the Research Division Head determines whether the beamline will be permitted to operate under the proposed beam conditions. If so, then Phase II of the shielding assessment for that beamline will proceed to find solutions for the identified exceptions.

- In the Phase II process the RSO, in collaboration with the beamline physicist, designs and implements an appropriate solution to each exception. This process proceeds as described in the Research Division Shielding Assessment Methodology document.

- The Phase II proposed solutions are reviewed by the ES&H Department and approved by the Director.

- Phase III consists of checking and documenting that any modifications to the beamline or shielding that were required by the Phase II analysis have been correctly implemented.

- The final spreadsheets and all the accompanying documentation are submitted to the Research Division Head and then to the ES&H Section Head for review and approval. The Spreadsheet Adjustment Document and spreadsheets produced in the Phase I process will be signed by the RSO who originated it, the Research Division Head or designee, and the ES&H Section Head or designee. The Phase II and Phase III documents are signed by their originators and those who checked the modifications. All these documents are collected in binders maintained by the Radiation Safety Group.

- Drawings in the Radiation Safety series, produced for the original RD Shielding Asssessment, are updatedto reflect changes made for the Incremental Shielding Assessment. As-Built Approvals for these drawings are signed by the Research Division Head, the Senior Laboratory Safety Officer, and the Director, or their designees.

1.8 Phase III Certifications

- Phase III documents consist of Filemaker Pro records listing the Phase II items, which represent recommended solutions to the shielding problems identified in Phase I. When each solution has been implemented, a responsible person on the shielding-assessment team initials the item's line on the Phase III document. When all solutions on a page or "record" are complete, the page is signed by those who originate and check the solutions. Necessary additional documentation is also noted on the form.

- In a few instances, the adopted solution to a problem may be different from the one recommended in the Phase II documents. In such cases, the new solution is documented in the Spreadsheet Adjustment Document before the Phase III document is signed off.

2. Spreadsheet Description

The results of the shielding assessment for a given beamline are summarized in three spreadsheets; one for each of the three assessment types. Each spreadsheet contains a block of cells defining the proposed accelerator limits and secondary beamline yields relevant to the assessment. In the case of the Longitudinal and Transverse spreadsheets, these limits are used to adjust the required amount of dirt for each Cossairt Category. The adjusted requirements are then compared against the actual thicknesses to see if the shielding is adequate over the corresponding Z-range or beam station. In the Labyrinths and Penetrations spreadsheet it is the calculated dose rate which is scaled and then compared against the limits dictated by the Fermilab Radiological Controls Manual. In both cases regions which fail to meet the new requirements are automatically flagged. Thus once a spreadsheet is constructed it is simply a question of changing a couple of numbers in order to ascertain the impact of any change in the accelerator parameters.

Note that only the cells containing the proposed accelerator parameters can be changed at will in an analysis. All other changes to the spreadsheets must be justified, approved and documented in the shielding documentation. In designing the spreadsheets consideration has been given to reducing as far as possible any risk of clerical errors when altering data. Thus imbedded formulae and cross-references to other cells and spreadsheets are used to reduce the differences between rows to as few columns as possible; thereby making modifications to the spreadsheet as simple and transparent as can be reasonably achieved.

The following three sections describe in detail the contents of each of the above spreadsheets and any other spreadsheets on which they depend. In these sections a brief description of the "volatility" of each cell or column is included:

- **Survey Data:** Raw survey data. Can only be changed as a result of new measurements.
- **Formula:** Value is calculated from other cells using an EXCEL formula. Changing the formula requires documentation and review.
- **Reference:** Contains a reference to another spreadsheet. Should not be changed.
- **Review Data:** Changing the data in these cells requires documentation and review.
- **Informational Data:** The data in these cells is of an informational nature and should be changed only by the RD/OD Beams Group Documentation Manager.
- **User Data:** The values in these cells can be freely adjusted to match the current assessment needs.

The last section describes how and where the spreadsheets are maintained and accessed.

2.1 Longitudinal

To evaluate shielding overburden longitudinally, above a beamline, three EXCEL spreadsheets are employed:

1. "*XX* Berm" spreadsheets, where *XX* is the two-letter code for a beamline, contain survey data points. They are updated whenever the Alignment Group provides data from a new aerial or optical survey.

2. "*XX* Deltas" spreadsheet, defines the Z-ranges used in the assessment for the *XX* beamline and averages data from "*XX* Berm" over these ranges to determine the average change in shielding thickness for each range.

3. Spreadsheets entitled "*XX*" contain the actual longitudinal shielding evaluations for the Z-ranges defined in "*XX* Deltas". It contains information on the amount of shielding required for the range (Cossairt Category, beam classification, and proposed parameters), the amount of shielding that exists (shielding thickness determined during the 1990 shielding assessment and changes obtained from "*XX* Deltas"), and information about any special considerations that affect the amount of shielding required.

2.1.1 "*XX* Berm" Spreadsheet

Individual Cell Definitions.

A1. TITLE: **(Informational Data)** Text reading "*XX* beamline," where *XX* is the two-letter code for the beamline to which the data applies.

Column Definitions.

A. BEAM STATION: **(Survey Data)** Location along beamline, in Alignment Group notation.

B. BEAM ELEV.: **(Survey Data)** Elevation, in feet above sea level, of beamline at this station.

C. BASE BERM ELEV.: **(Survey Data)** Elevation, in feet above sea level, of berm surface immediately above beamline, interpolated from points in 1988 aerial survey files or subsequent optical surveys. The uncertainty in these numbers due to the aerial survey technique is about 0.5 ft.

D. CURRENT BERM ELEV.: **(Survey Data)** Elevation, in feet above sea level, of surface immediately above beamline, interpolated from points in the latest aerial survey files.

E. DIFFERENCE: **(Formula)** Difference, in feet, between "Current Berm Elev." (column D) and "Base Berm Elev." (column C).

F. Z COORDINATE: **(Formula)** Position along the beamline measured in feet. Obtained by parsing "Beam Station" (column A) to remove the embedded "+" and converting the string to a number.

2.1.2 "*XX* Deltas" Spreadsheet

Individual Cell Definitions.

B1. TITLE: **(Informational Data)** Text reading "*XX* LONGITUDINAL BERM CHANGES," where *XX* is the two-letter code for the beamline.

Column Definitions.

A. Z-RANGE: **(Review Data)** Endpoints of range measured in feet along the beamline and separated by a hyphen. This column defines the Z-ranges used in the assessment.

B. CHANGE IN SHIELDING: **(Formula)** Difference, in feet, between newest aerial survey and base surveys, averaged over all sampled stations within the Z-range specified in column A. Value is derived from Column E of the "*XX* Berm" spreadsheet by averaging the column E values of all rows of "*XX* Berm" whose column F lies within the Z-range specified.

C. INITIAL Z: **(Formula)** Z-coordinate, in feet, of beginning of range, derived from the string in column A. Used in the calculation performed in column B.

D. FINAL Z: **(Formula)** Z-coordinate, in feet, of end of range, derived from the string in column A. Used in the calculation performed in column B.

E. LENGTH IN Z: **(Formula)** Difference, in feet, between final Z (column D) and initial Z (column C). This column is of informational value only.

2.1.3 "*XX*" Spreadsheet

Individual Cell Definitions.

A1. TITLE: **(Informational Data)** Indicates which beamline the spreadsheet refers to.

M1. DATE: **(Formula)** Date the spreadsheet was calculated.

F2. BASE PRIMARY BEAM ENERGY: **(Review Data)** Energy, in GeV, of primary beam used in calculations from which the Cossairt Criteria were derived.

F3. BASE PRIMARY BEAM INTENSITY: **(Review Data)** Intensity, in protons per Tevatron cycle, of primary beam used in calculations from which the Cossairt Criteria were derived.

M2. PRIMARY BEAM ENERGY: **(User Data)** Energy, in GeV, of primary beam assumed in the current assessment.

M3. PRIMARY BEAM INTENSITY: **(User Data)** Intensity, in protons per Tevatron cycle, of primary beam assumed in the current assessment.

M4. SECONDARY BEAM ENERGY: **(User Data)** Maximum energy, in GeV, of the secondary beam (if any) assumed in the current assessment.

M5. SECONDARY YIELD: **(User Data)** Maximum yield of secondary particles (if any) per incident primary proton assumed in the current assessment.

M6. ACCELERATOR CYCLE TIME: **(User Data)** Time, in seconds, for a full Tevatron extraction cycle.

O3. (UNLABELED) PRIMARY SHIELDING CORRECTION: **(Formula)** Value, in feet, to be *subtracted* from "Standard" required shielding (column I) in order to obtain the amount of shielding required for the current assessment. This value is arrived at by scaling from the base beam parameters, F2 & F3, to the current parameters, M2-M6. This value is only used for Z-ranges declared as regions of primary beam. The formula used is :

$$\Delta = 2.8 \cdot \log_{10}\left(\frac{M6}{57} \cdot \frac{F3}{M3} \cdot \left(\frac{F2}{M2}\right)^{0.8}\right)$$

O5. (UNLABELED) SECONDARY SHIELDING CORRECTION: **(Formula)** Similar to O3 above, but for use in regions of secondary beam. The formula used is:

$$\Delta = 2.8 \cdot \log_{10}\left(\frac{M6}{57} \cdot \frac{F3}{M3 \cdot M5} \cdot \left(\frac{F2}{M4}\right)^{0.8}\right)$$

<u>Column Definitions.</u>

A. Z-RANGE: **(Reference)** Upstream and downstream limits, in feet, of beamline segment. Value comes from Column A of "*XX* Deltas" Longitudinal spreadsheet.

B. ENCLOSURE TYPE: **(Informational Data)** Brief text identifier for enclosure names and pipe segments.

C. BEAM TYPE: **(Review Data)** Value "P" for primary protons, "S" for secondary beams. Used to determine which correction factor (O3 or O5) is used in calculating the required shielding thickness for the current assessment.

D. FIXED SHIELDING: **(Review Data)** Amount of fixed shielding, including soil overburden and buried shielding, as determined from the 1988 aerial survey, previous shielding assessments, and subsequent reviews. Units are in equivalent feet of dirt.

E. REMOVABLE SHIELDING: **(Review Data)** Amount of removable shielding, such as concrete shield blocks, target dumps, etc., used to determine the current amount of existing shielding. Units are in equivalent feet of dirt.

F. CHANGE IN SHIELDING: **(Reference)** Difference in ground elevation between 1988 aerial survey and current survey measured in feet. Obtained from the column B of the spreadsheet "*XX Deltas*".

G. CURRENT SHIELDING: **(Formula)** Currently existing shielding. This is the sum of three preceding columns. Units are equivalent feet of dirt.

H. COSSAIRT CATEGORY: **(Review Data)** Category classifying this beamline segment according to D. Cossairt's memo of 11 December 1990, titled "*Generic Shielding Criteria for Compliance with Chapter 6 of the Fermilab Radiation Guide*".

I. STANDARD: **(Formula)** Required amount of shielding for this Z-range as determined by the Cossairt Category given in column H.

J. REQUIRED: **(Formula)** Amount of shielding, in equivalent feet of dirt, required for this Z-range given the beam parameters in M2-M6. This is calculated by subtracting the appropriate correction factor (O3 or O5 depending on column C) from the value found in column I.

K. DIFFERENCE: **(Formula)** Difference between "Current Shielding" (column G) and "Required" (column J), in equivalent feet of dirt. The Current Shielding is adequate for the proposed beam conditions if it is within 0.5 feet of or exceeds that required.

L. PAST SOLUTIONS: **(Formula)** If the current shielding is not adequate then a list of possible solutions from column O is displayed. These are solutions which were applicable in past assessments and could be one or more of the following.

- IM : An interlocked intensity monitor was used to reduce the maximum accident condition to a single spill accident. This effectively gains 2 feet of shielding credit. This cannot be used with Cossairt Categories involving interlocked detectors (i.e., categories 6 through 11).
- NH : Indicates that the beamline geometry in this Z-range was shown to be a "No Hit" region. In such a region the beam is geometrically constrained so as not to be able to hit any beamline components. Under these conditions the required shielding is reduced by roughly 11 feet of dirt.
- RT : This flag may accompany a NH flag. It indicates that certain beamline elements have been "Red Tagged" in order to ensure the "No Hit" argument. This flag has no affect on the shielding requirements.
- *n* : A number indicates that a geometry specific calculation was done for the region which resulted in *n* feet of shielding credit.

M. AFTER SOLUTIONS: **(Formula)** This column gives the difference between the current and required shielding after allowance has been made for the solutions listed in column L. It is left blank if the solutions were not required and is equal to column K if there were no past solutions.

N. FAIL?: **(Formula)** If column M contains a value less than -0.5 feet, then an X will appear in this column. This flags regions in which the current shielding is deficient for the proposed beam conditions despite any allowances for previous solutions.

The following columns are not included in printed reports but are present in the spreadsheet.

O. OLD SOLUTIONS: **(Review Data)** Contains condition codes describing solutions which have been used in previous fixed-target runs to reduce the shielding requirements for this Z-range. The recognized codes are described above (see column L).

P. SPECIAL CREDIT: **(Formula)** Contains a numerical representation of any shielding credit obtained from special calculations. For use in column M.

2.2 Transverse

To evaluate the shielding as measured transversely to the beamline at specially selected locations, the program THICK (described in detail in a later section) is used to produce a spreadsheet containing the information about the current shielding thickness. This spreadsheet is referenced by a second spreadsheet designed to look and function like the final Longitudinal spreadsheet. As in the Longitudinal case information about the shielding requirements and special considerations is compared to the current shielding thickness as determined by THICK. The spreadsheet entries containing THICK results are all classified as "Survey Data" and are based on an analysis of berm and enclosure surveys.

2.2.1 "*XX* Thicknesses" Spreadsheet

Individual Cell Definitions.

A1. TITLE: **(Informational Data)** Indicates which beamline the spreadsheet refers to.

Column Definitions.

A. STATION: **(Survey Data)** This column contains a seven character identifier, *BBESSS*, defining the location at which the transverse shielding evaluation is done. *BB* is the beamline to which all survey measurements are referenced (not necessarily the same as *XX*), *E* indicates the nearest upstream enclosure number, and *SSSS* is the station or Z-location at which the berm cross-section is measured.

B. SHIELDING W/O AIR: **(Survey Data)** Minimum thickness of shielding, in equivalent feet of dirt, found by the program THICK and without taking into consideration the effects of air gaps.

C. SHIELDING WITH AIR: **(Survey Data)** Minimum thickness of shielding as determined by the program THICK and taking into consideration the effect of air gaps on dose rates. This is the number actually used in the shielding assessment.

D. BEAM OFFSET: **(Survey Data)** Horizontal distance of beam from reference beamline specified in column A.

E. BEAM ELEVATION: **(Survey Data)** Elevation of beam centerline measured in feet above sea level.

2.2.2 "*XX*" Spreadsheets

Individual Cell Definitions.

A1. TITLE: **(Informational Data)** Indicates which beamline the spreadsheet refers to.

M1. DATE: **(Formula)** Date the spreadsheet was calculated.

F2. BASE PRIMARY BEAM ENERGY: **(Review Data)** Energy, in GeV, of the primary beam used in calculations from which the Cossairt Criteria were derived.

F3. BASE PRIMARY BEAM INTENSITY: **(Review Data)** Intensity, in protons per Tevatron cycle, of primary beam used in calculations from which the Cossairt Criteria were derived.

M2. PRIMARY BEAM ENERGY: **(User Data)** Energy, in GeV, of the primary beam assumed in the current assessment.

M3. PRIMARY BEAM INTENSITY: **(User Data)** Intensity, in protons per Tevatron cycle, of primary beam assumed in the current assessment.

M4. SECONDARY BEAM ENERGY: **(User Data)** Maximum energy, in GeV, of the secondary beam (if any) assumed in the current assessment.

M5. SECONDARY YIELD: **(User Data)** Maximum yield of secondary particles (if any) per incident primary proton assumed in the current assessment.

M6. ACCELERATOR CYCLE TIME: **(User Data)** Time, in seconds, for a full Tevatron extraction cycle.

O3. (UNLABELED) PRIMARY SHIELDING CORRECTION: **(Formula)** Value, in feet, to be *subtracted* from "Standard" required shielding (column I) in order to obtain the amount of shielding required for the current assessment. This value is arrived at by scaling from the base beam parameters, F2 & F3, to the current parameters, M2-M6. This value is only used for Z-ranges declared as regions of primary beam. The formula used is:

$$\Delta = 2.8 \cdot \log_{10}\left(\frac{M6}{57} \cdot \frac{F3}{M3} \cdot \left(\frac{F2}{M2}\right)^{0.8}\right)$$

O5. (UNLABELED) SECONDARY SHIELDING CORRECTION: **(Formula)** Similar to O3 above, but for use in regions of secondary beam. The formula used is:

$$\Delta = 2.8 \cdot \log_{10}\left(\frac{M6}{57} \cdot \frac{F3}{M3 \cdot M5} \cdot \left(\frac{F2}{M4}\right)^{0.8}\right)$$

Column Definitions.

A. TRANSVERSE STATION: **(Reference)** Location, in feet along beamline, of transverse cross-section evaluated in this row. Value from Column A of "*XX* Thicknesses" spreadsheet.

B. ENCLOSURE TYPE: **(Informational Data)** Brief text identifier for enclosure names and pipe segments.

C. BEAM TYPE: **(Review Data)** Value "P" for primary protons, "S" for secondary beams. Used to determine which correction factor (O3 or O5) is used in calculating the required shielding thickness for the current assessment.

D. REMOVABLE SHIELDING: **(Informational Data)** The data in this column is used to indicate that the shielding calculation assumed that some amount of removable shielding was present. For simple geometries it contains the amount of removable shielding, such as concrete shield blocks, target dumps, etc., assumed in the calculation. Units are in equivalent feet of dirt. If the station represents a labyrinth or enclosure constructed from shielding blocks this column indicates the fact with the word *Blocks*.

E. BEAM ELEVATION: **(Reference)** Elevation of beamline at this station. Obtained from Column E of "*XX* Thicknesses" spreadsheet. This data is of informational value only and is provided to assist in the review process.

F. SHIELDING W/O AIR: **(Reference)** Minimum thickness of shielding without taking into account the effects of air gaps. Obtained from column B of "*XX* Thicknesses" spreadsheet. This data is of informational value only and is provided to assist in the review process.

G. SHIELDING WITH AIR: **(Reference)** Minimum thickness of shielding including corrections for the effects of air gaps. Obtained from column C of "*XX* Thicknesses" spreadsheet.

H. COSSAIRT CATEGORY: **(Review Data)** Category classifying this beamline segment according to D. Cossairt's memo of 11 December 1990, titled "*Generic Shielding Criteria for Compliance with Chapter 6 of the Fermilab Radiation Guide*".

I. STANDARD: **(Formula)** Required amount of shielding for this Z-range as determined by the Cossairt Category given in column H.

J. REQUIRED: **(Formula)** Amount of shielding, in equivalent feet of dirt, required for this Z-range given the beam parameters in M2-M6. This is calculated subtracting the appropriate correction factor (O3 or O5 depending on column C) from the value found in column I.

K. DIFFERENCE: **(Formula)** Difference between "Shielding with Air" (column G) and "Required" (column J), in equivalent feet of dirt. The Current Shielding is adequate for the proposed beam conditions if it is within 0.5 feet of or exceeds that required.

L. PAST SOLUTIONS: **(Formula)** If the current shielding is not adequate then a list of possible solutions from column O is displayed. These are solutions which were applicable in past assessments and could be one or more of the following:

IM : An interlocked intensity monitor was used to reduce the maximum accident condition to a single spill accident. This effectively gains 2 feet of shielding credit. This cannot be used with Cossairt Categories involving interlocked detectors (i.e., categories 6 through 11).

NH : Indicates that the beamline geometry in this Z-range was shown to be a "No Hit" region. In such a region the beam is geometrically constrained so as not to be able to hit any beamline components. Under these conditions the required shielding is reduced by roughly 11 feet of dirt.

RT : This flag may accompany a NH flag. It indicates that certain beamline elements have been "Red Tagged" in order to ensure the "No Hit" argument. This flag has no affect on the shielding requirements.

n : A number indicates that a geometry specific calculation was done for the region which resulted in *n* feet of shielding credit.

M. AFTER SOLUTIONS: **(Formula)** This column gives the difference between the current and required shielding after allowance has been made for the solutions listed in column L. It is left blank if the solutions were not required and is equal to column K if there were no past solutions.

N. FAIL?: **(Formula)** If column M contains a value less than -0.5 feet, then an X will appear in this column. This flags regions in which the current shielding is deficient for the proposed beam conditions despite any allowances for previous solutions.

The following columns are not included in printed reports but are present in the spreadsheet.

O. OLD SOLUTIONS: **(Review Data)** Contains condition codes describing solutions which have been used in previous fixed-target runs to reduce the shielding requirements for this Z-range. The recognized codes are described above (see column L).

P. SPECIAL CREDIT: **(Formula)** Contains a numerical representation of any shielding credit obtained from special calculations. For use in column M.

2.3 Labyrinths and Penetrations

Only one spreadsheet per beamline is used for the Labyrinths and Penetrations evaluation. It is called "*XX*," where *XX* is the Research Division two-letter code for the beamline. Each spreadsheet contains a number of rows for labyrinths, followed by another group of rows for penetrations. Both these tables function identically. This spreadsheet works analogously to the Longitudinal and Transverse spreadsheets. The difference is that instead of comparing shielding thicknesses, the spreadsheet compares dose rates expected at the labyrinth or penetration entrance with those permitted by the Fermilab Radiological Control Manual. All dose rates are measured in mrem per accelerator cycle.

2.3.1 "*XX*" Spreadsheets

Individual Cell Definitions.

A1. TITLE: **(Informational Data)** Indicates which beamline the spreadsheet refers to.

K1. DATE: **(Formula)** Date the spreadsheet was calculated.

E3. BASE PRIMARY BEAM ENERGY: **(Review Data)** Energy, in GeV, of the primary beam assumed in the initial calculations of the accident condition dose rates.

E4. BASE PRIMARY BEAM INTENSITY: **(Review Data)** Intensity, in protons per Tevatron cycle, of the primary beam assumed in the initial calculations of the accident condition dose rates.

K3. PROPOSED PRIMARY BEAM ENERGY: **(User Data)** Energy, in GeV, of the primary beam assumed in the current assessment.

K4. PROPOSED PRIMARY BEAM INTENSITY: **(User Data)** Intensity, in protons per Tevatron cycle, of primary beam assumed in the current assessment.

K5. PROPOSED SECONDARY BEAM ENERGY: **(User Data)** Maximum energy, in GeV, of the secondary beam (if any) assumed in the current assessment.

K6. PROPOSED SECONDARY YIELD: **(User Data)** Maximum yield of secondary particles (if any) per incident primary proton assumed in the current assessment.

K7. ACCELERATOR CYCLE: **(User Data)** Time, in seconds, for a full Tevatron extraction cycle.

M4. (UNLABELED) PRIMARY SCALE FACTOR: **(Formula)** Value used to scale the Calculated Base Dose (column F) for regions of primary beam to the assumed beam parameters in cells K3 and K4. The formula used to determine this factor is:

$$F = \left(\frac{K3}{E3}\right)^{0.8} \cdot \frac{K4}{E4}$$

M6. (UNLABELED) SECONDARY SCALE FACTOR: **(Formula)** Value used to scale the Calculated Base Dose (column F) for regions of secondary beam to the assumed beam parameters in cells K4 to K6. The formula used to determine this factor is:

$$F = \left(\frac{K5}{E3}\right)^{0.8} \cdot \frac{K4 \cdot K6}{E4}$$

Column Definitions.

A. ENCLOSURE: **(Informational Data)** Enclosure name using Research Division naming convention.

B. (UNLABELED) BEAM TYPE: **(Review Data)** Value "P" for primary protons, "S" for secondary beams. Used to determine which correction factor (M4 or M6) is used in calculating the expected dose rate for the current assessment.

C. Z-LOCATION: **(Informational Data)** Location, in feet, of labyrinth or penetration along direction of beamline.

D. WORKSHEET PWKS#: **(Review Data)** Reference to RD Shielding Assessment document describing the dose calculations for this labyrinth or penetration. These calculations are discussed in the RD Shielding Assessment Methodology binder, in "Labyrinths and Penetrations Methodology Version 1.3," by R. Rameika.

E. REMOVABLE SHIELDING: **(Informational Data)** The data in this column is used to indicate that the dose rate calculation assumed that some amount of removable shielding was present. For simple geometries it contains the amount of removable shielding, such as concrete shield blocks, target dumps, etc., assumed in the calculation. Units are in equivalent feet of dirt. If the location is a labyrinth constructed from shielding blocks this column indicates the fact with the word *Blocks*. If the worksheet calculation assumed a penetration to be partially or completely filled, this column indicates the fact with the word *filled*.

E. REMOVABLE SHIELDING: **(Review Data)** Amount of removable shielding, such as concrete shield blocks, target dumps, etc., used in the dose rate calculations. Units are in equivalent feet of dirt.

F. BASE DOSE: **(Review Data)** Radiation dose, in mrem/pulse, at the outside entrance to the labyrinth or penetration. Derived from the worst case calculation from the worksheet referenced in column D. The numbers actually entered in the spreadsheet have been scaled from the worksheet calculations to the values expected for the beam conditions specified in E3 and E4. They have also been converted to mrem/pulse

G. COSSAIRT CATEGORY: **(Review Data)** Category classifying this location according to D. Cossairt's memo of 11 December 1990, titled "*Generic Shielding Criteria for Compliance with Chapter 6 of the Fermilab Radiation Guide*".

H. ALLOWED DOSE: **(Formula)** Maximum dose, in mrem/pulse, allowable at this location given the Cossairt classification in column G. The dose rates are taken from the Fermilab Radiological Control Manual and where necessary converted from mrem/hour to mrem/pulse using the proposed accelerator cycle time in K7.

I. DOSE FOR PROPOSAL: **(Formula)** Expected worst case dose rates for the proposed beam parameters. This value is obtained by simply scaling the base value in column F by the appropriate scale factor (M4 or M6) depending on the beam type in column B.

J. PAST SOLUTIONS: **(Formula)** If the Base Dose calculation assumed an "off-axis" beam loss then this is noted in this column. Also, if the dose for the proposed beam conditions exceeds the allowed dose, then a list of possible solutions from column M is displayed. These are solutions which were applicable in past assessments and could be one or more of the following:

- IM : An interlocked intensity monitor was used to reduce the maximum accident condition to a single spill accident. This effectively increases the Allowed Dose by a factor of 360 / K7. This cannot be used with Cossairt Categories involving interlocked detectors (i.e., categories 6 through 11).
- NH : Indicates that the beamline geometry at this location was shown to be a "No Hit" region. In such a region the beam is geometrically constrained so as not to be able to hit any beamline components. Under these conditions the accident dose is reduced by a factor of roughly $1.7 \infty 10^4$.
- RT : This flag may accompany a NH flag. It indicates that certain beamline elements have been "Red Tagged" in order to ensure the "No Hit" argument. This flag has no affect on the shielding requirements.
- BP : Indicates that this region contains only a thin beam pipe and hence the accident dose is reduced by a factor of 5.
- OFF : Indicates that the dose rate calculation for this location assumed an "off-axis" accident condition. This flag is supplied for review purposes only.

K. DOSE WITH SOLUTIONS: **(Formula)** This column gives the dose, in mrem/cycle, after corrections for past solutions have been applied. It is blank if the dose calculated in column I is less than the allowed dose in column H.

L. FAIL?: **(Formula)** If column K contains a value less than column H, then an X will appear in this column. This flags regions in which the current shielding is deficient for the proposed beam conditions despite any allowances for previous solutions. In making the comparison with column H, account is taken of solution codes in column J which affect the allowed dose rate.

The following columns are not included in printed reports but are present in the spreadsheet.

M. SOLUTION CREDITS: **(Review Data)** Contains condition codes describing solutions which have been used in previous runs to reduce the shielding requirements for this location. The recognized codes are described above (see column J).

N. NET ATTENUATION OF CREDITS: **(Formula)** This column contains the attenuation factor derived from the codes in column M and used in calculating the dose rate in column K.

2.4 Maintenance

The Incremental Assessment spreadsheets are maintained in the Operations Department's VAXshare area, in the folder "Shielding." Only the RD/OD Beams Group Documentation Manager and the Department Head have write access to this area. Hard copies of the latest reviewed and approved versions of these spreadsheets are kept in the RD Shielding Documentation folders along with the corresponding Spreadsheet Adjustment Document.

Whenever, a new Incremental Assessment is performed, the current spreadsheets are compared against the approved hard copies and any differences should be either rectified or documented in a new Spreadsheet Adjustment Document. This ensures that no undocumented or unauthorized changes can be made to the spreadsheets.

3. Methodology for Incorporating Survey Data

Survey data, derived from aerial photography, are maintained by the Alignment Group in a CAD system known as VANGO. In general, shielding assessment personnel request surface elevation data for a set of locations from the Alignment Group. Then the data are transformed into Incremental Shielding Assessment spreadsheets.

For complete details of the data source, refer to "Fermilab Digital Contour and Planimetric Aerial Photo Database and Software Interface Documentation" by Terry Sager, dated 17 June 1991. This document may be found in the "Aerial Survey" section of the "Methodology" volume of the Research Division Shielding Assessment collection.

3.1 Longitudinal

The spreadsheets for longitudinal shielding assessment require values for the elevations of a berm directly above the centerline of the beam.

Longitudinal assessment begins with a request to the Alignment Group for flyover data for a beamline.

They provide data in the form of an ASCII file on the FNALV Vax cluster. The values include beamline station number, elevations for the original 1988 aerial survey, elevations for the latest survey, and the difference between the two. Elevation of the beam itself at each station are also included, though this information is not used by the assessment spreadsheets.

The latest survey may include elevations acquired from ground-based surveyors in addtion to aerial photogrammetric data.

The Documentation Manager converts this ASCII file into a Microsoft Excel spreadsheet running on an Apple Macintosh. He adds a column converting station number (such as "28+47") into floating-point values (such as 2847.00).

The resulting spreadsheet is referenced by the longitudinal "XX Deltas" spreadsheet, which uses the elevation data to calculate average change in elevation over a range of stations. (Here "XX" stands for the two-letter code that names a beamline in the Research Division's nomenclature.)

3.2 Transverse

To evaluate shielding perpendicular to the beamline, transverse cross-sections of the surface nearby are obtained from aerial survey data. Each cross-section represents a set of elevations and transverse (horizontal) offsets at a fixed station (Z-coordinate) along the beamline.

The choice of stations for evaluating cross-sections was based on those stations analyzed in the original shielding assessment project. Additional stations have been added at the request of Radiation Safety Officers.

The starting point of the analysis is a "geometry" file which defines enclosure walls, shielding blocks, target piles, and other structural elements which affect shielding. This file is named XX.XVANS (for a beamline named XX).

In order to make the process of obtaining VANGO cross-section data reproducible, and to minimize the introduction of clerical errors, the process has been partly automated. A script macro called XSEC has been created by the Alignment Group. The Documentation Manager extracts a list of desired stations from the geometry file, and creates an input file with the information required by XSEC. Then he runs XSEC; the result is a number of files containing cross-section elevations. These are collected into a file "XX.BERMS," which will be used by the THICK program to calculate minimum shielding paths. (For a detailed description of this software and its input files, see the section "Program for Calculating Minimum Transverse Shielding-- THICK.")

Both the XX.BERMS file and the XX.XVANS file are inputs to THICK. The output is a file (XX_THICKNESSES.) containing station number and reference beamline, length of minimum-shielding paths for a beam loss at that station assuming no attenuation across air gaps, and path length assuming credit for inverse-square attenuation across air gaps. Beam offset from the reference beamline and beam elevation are also included for convenience, though they are not used in the Excel calculations.

The Documentation Manager converts the XX_THICKNESSES file into an Excel spreadsheet. Values in this spreadsheet are referenced by the transverse "XX" spreadsheet, and the minimum-shielding path "without air" is used to test whether the shielding is sufficient.

where the factor 2.8 represents the amount of dirt required to produce a dose rate attenuation of 10, The second term is constructed to ensure that the correction is zero for an air gap of 3' immediately surrounding the beam. The R=0.0 situation only applies to beam pipes in enclosures.

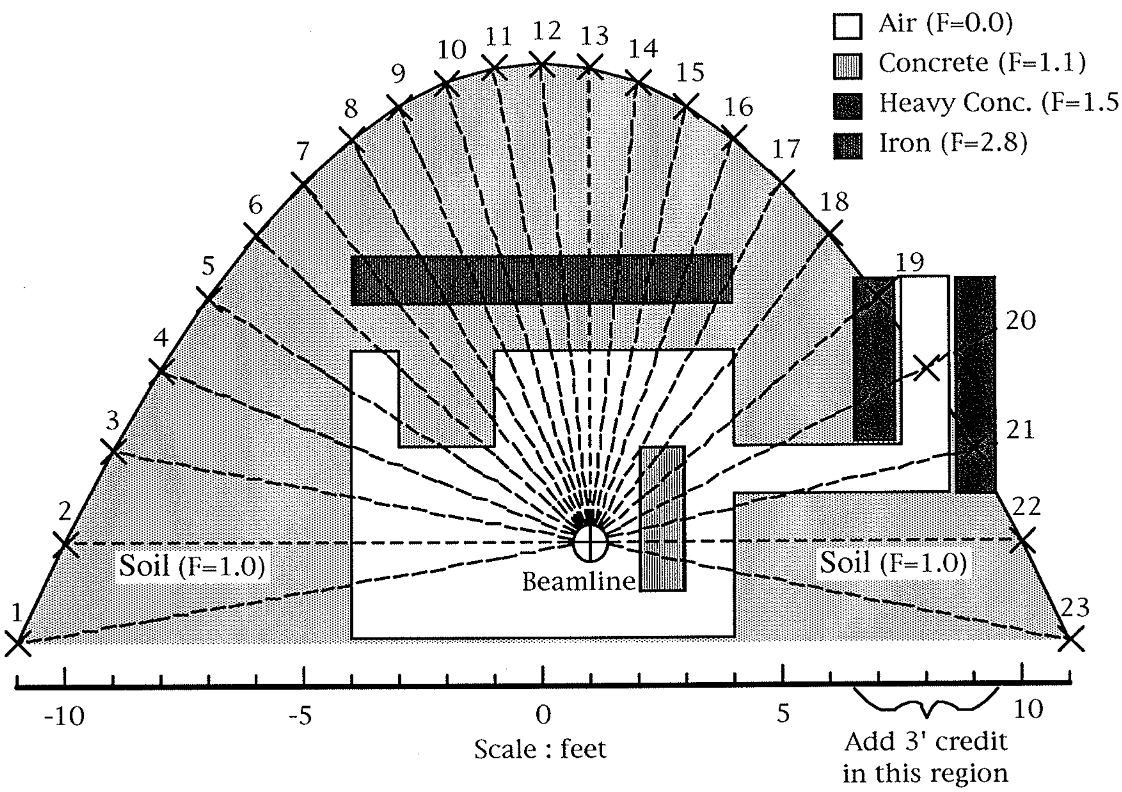
- Step 8. For each beam station, the results obtained in steps 5 through 7, are used to determine the points at which the shielding thickness is at a minimum both with and without the air gap correction. These minimum thicknesses are written to the output file along with the beam station identifier and the beam elevation. The shielding thickness calculated with the air gap correction is the value used in the assessment; the other numbers are supplied to facilitate subsequent review processes.

- Step 9. For each beam station the program produces a file named *station*.KUMAC, where *station* is the station identifier. This file is a PAW macro which draws the geometry used with the berm profile superimposed. This drawing also includes the ray(s) at which the minimum shielding occurred and an indication of which regions received extra shielding credit as described in step 6. These drawings are used to facilitate the review process and the phase II shielding assessment.

4.2 Self-Test Feature

If no geometry file is given the program goes into a self-test mode in which a built-in geometry and berm profile are analyzed with the same routines used to do a real measurement of shielding thickness. This feature is supplied in order to ensure that the program is working correctly and is to be used whenever modifications to the program are made.

The geometry used for the self-test is shown below. It contains all the possible complications that may be encountered in real enclosures. The output of the program is a table which contains the X and Y coordinates of the berm points. The length of the ray used to determine the shielding thickness, the actual shielding thickness, and the value of the calculated air gap correction. These values should agree with the ones listed in the following table.



*** ERROR: No enclosure shape ***
This error is generated while the program is calculating thicknesses. It indicates that no enclosure shape was defined even though the beam position is inside one of the defined shapes. The station identifier will precede the message.

*** ERROR: Beam not in enclosure ***
This error is generated while the program is calculating thicknesses. It indicates that the beam position as defined by the BEAM card, is not inside the enclosure shape. The station identifier will precede the message.

*** ERROR: Bad geometry detected ***

This error is generated while the program is calculating thicknesses. It is followed by the coordinates of the beam and the current berm point, and a list of distances and shape identifiers. The distances are from the beam to the shape boundary. The shape identifiers are just sequence numbers indicating the order in which the shapes occur in the geometry file. This message is usually generated if two shape boundaries overlap or are degenerate. The accompanying list should help locate the problem. The station identifier will precede the message.

4.5 Note on Aboveground Enclosures

Where an enclosure is entirely above ground with no earth overburden, so overflight data is not appropriate for calculating its thickness, add a thick steel floor to the enclosure to force THICK to choose a ray that passes through the walls or ceiling.

4.6 Maintenance and Access

One of the duties of the RD/OD Beams Group is to maintain and distribute software used in beamline design and shielding calculations. The THICK program is included in this maintenance and distribution system. The source code for the program is maintained in a project area on the Fermilab Central VAX Cluster. Changes to the source code in this area are managed by CMS, a commercial code management product, and access is controlled by way of protection codes. Only the author and the Beams Group Code Manager are authorized to make changes and only the Code Manager can produce a RELEASE version of the program. Before producing a RELEASE the Code Manager must verify that the program is working correctly by running the self-test feature. Note that CMS automatically records a history of all modifications made to the source code as it is developed and improved over time. The source code is built into object libraries which are located in the project area and are distributed to project areas on other clusters and machines at Fermilab.

The Beams Group provides command procedures which allow users to build executables from the distributed libraries, and run those executables on their machines. The setup procedure used to access the project areas will define a command which enables access to the THICK program. Typing SETUP_THICK will give information about the program and define a command RUN_THICK which is used to produce the executable and run the program. The RUN_THICK command will also prompt for definitions, if any, for the input and output files, and will check that the user's local area contains no files (such as spurious berm data files) that might interfere with the operation of the program.