ACKNOWLEDGMENT

The opinions, findings, and conclusions expressed in this paper are ours and not necessarily those of the Federal Highway Administration.

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STAMINA 1.0 Experiences on the Dulles Access Highway Extension Project

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In anticipation of the construction of the long-awaited and controversial Dulles Access Highway Extension project between Route 123 and I-66 in Fairfax County, Virginia, the Federal Highway Administration (FHWA) sought to evaluate potential noise impacts by using the most advanced tools available. Accordingly, the project was analyzed by using the Standard Method in Noise Analysis program (STAMINA 1.0), the level 2 computer program version of the FHWA Highway Traffic-Noise-Prediction Model. This paper discusses that analysis in terms of project impacts and provides an evaluation of STAMINA 1.0 performance. Insight is also given into use of STAMINA 1.0 as a tool to optimize the cost-effectiveness of noise barriers.

In its effort to provide the best-possible analysis of noise impacts from the proposed Dulles Access Highway Extension (DAHE) project, the Federal Highway Administration (FHWA) made an early decision to use the most-advanced prediction methodology available. This methodology is the STAMINA 1.0 computer program (1), which is the level 2 version of the FHWA Highway Traffic-Noise-Prediction Model (2).

In the course of the DAHE noise analysis, much was learned about the strengths and limitations of STAMINA 1.0 as well as about the impacts of the project itself. This paper presents conclusions in each of these areas.

DAHE PROJECT BACKGROUND

The proposed DAHE project in Fairfax County, Virginia, is a four-lane controlled-access expressway owned by the Federal Aviation Administration (FAA). It is being designed by FHWA as a direct federal project under an agreement with FAA. The section analyzed for noise impacts in this study extends from VA-123 (Dolley Madison Boulevard) to Interstate 66, a distance of approximately 2 miles (Figure 1). The project is the last link in the Dulles Access Highway that connects the federally owned and operated Dulles Airport with the Washington, D.C., metropolitan area. DAHE was not constructed as part of the original highway in the 1960s because its usefulness was fully dependent on the implementation of I-66, which was delayed because of litigation; approval for construction by the Virginia Department of Highways and Transportation was finally given by the Secretary of Transportation on January 6, 1977 (3). A condition to that approval was that peak-hour, peak-direction traffic be limited to Dulles Airport traffic, carpools, buses, and emergency vehicles. In addition, trucks are to be banned from DAHE and I-66 at all times.

Completion of the DAHE project will provide the following services (3):

1. Improved access to and from Dulles Airport,
2. Direct, safe, and efficient access between I-66 and the northern half of I-495 (Capital Beltway),
3. Direct access to and from I-66 and Metro transit facilities for express commuter buses from the northwest quadrant of Fairfax County and eastern Loudoun County,
4. Improved access to and from Wolf Trap Farm Park for the Performing Arts, and
5. Improved traffic circulation in the areas adjacent to the project.

Even though the DAHE project was not scheduled for construction at the same time as the portion west of the Capital Beltway, right-of-way was purchased and set aside for the entire project shortly after the Dulles Airport location was selected in 1957. In the intervening years, residential development has occurred adjacent to most of the DAHE corridor (Figures 2 and 3). From the perspective of noise impacts, this virtual encroachment on the right-of-way is quite critical. Existing Leq noise levels for most of the residences are low [typically 50-55 dB(A)], which contributes to the quiet environment provided by the densely vegetated right-of-way zone. Construction of DAHE in that zone will introduce a new major noise source and increase noise levels at most receptors along the highway right-of-way.

Even though potential homeowners in the project vicinity should have been aware of the eventual construction of DAHE, FHWA assumed a commitment to minimize noise impacts to the extent feasible through the use of noise-abatement measures in the form of barriers. The design criteria established set a maximum increase of 10 dB(A) over the existing level for each sensitive receptor on the project.

Figures 4 and 5 present computer-generated renderings (photomontage) that show the expected visual impact of DAHE construction. It may be noticed that certain areas within the corridor, in particular Penguin Place (Figure 4, foreground), are not conducive to use of noise barriers due to the ruggedness of the terrain.

Figure 1. Project proposal; area studied is between VA-123 and I-66.

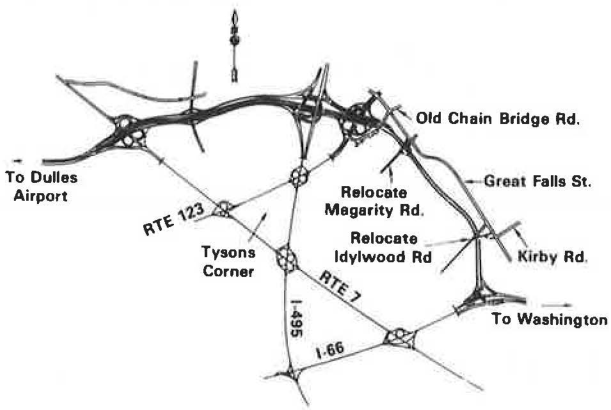


Figure 2. View toward the west from vicinity of Old Chain Bridge Road.

Figure 3. View toward the east from Magarity Road along right-of-way.

FHWA MODEL AND STAMINA 1.0

After a decade of research, development, and validation, the FHWA model currently stands as the state-of-the-art tool for highway noise prediction in this country. Use of this model is virtually and in effect required on all direct federal-aid highway projects on which noise impacts may occur. Expressed mathematically, the FHWA model states:

$$Leq(h)_i = (\bar{L}_o)_{E_i} + 10 \log(N_i \pi D_o / S_i T) + 10 \log(D_o/D)^{1+\alpha} + 10 \log[\psi_\alpha(\phi_1, \phi_2)/\pi] + \Delta_s \quad (1)$$

Figure 4. Photomontage view toward the west and Magarity Road from vicinity of Idylwood Road.

Figure 5. Photomontage view toward the west and Magarity Road.

where

$Leq(h)_i$ = hourly equivalent sound level of ith class of vehicles;
$(\bar{L}_o)_{E_i}$ = reference energy mean emission level of ith class of vehicles;
N_i = number of vehicles in ith class that pass a specified point during some specified time period (1 h);
D = perpendicular distance (m) from centerline of traffic lane to the observer;
D_o = reference distance at which emission levels are measured (15 m);
S_i = average speed of ith class of vehicles (km/h);
T = time period over which Leq is computed (1 h);
α = site parameter, the values of which depend on site conditions;
ψ = symbol that represents a function used for segment adjustments, i.e., an adjustment for finite-length roadways;
ϕ_i, ϕ_2 = angles measured between roadway segment and receiver; and
Δ_s = attenuation [dB(A)] provided by some type of shielding such as barriers, rows of houses, and densely wooded areas.

The FHWA model is considered the best available because of the characteristics of the parameters $(\bar{L}_o)_{E_i}$, α, and ψ_α. The parameter $(\bar{L}_o)_{E_i}$ represents a national reference energy mean emission level based on an extensive truck-measurement program conducted in the mid-1970s (4). Typically, the FHWA model uses three classes of vehicles: automobiles (two axles, four wheels), medium trucks (two axles, six tires), and heavy trucks (three or more axles). The values determined from the measurement study are as follows:

For automobiles:

$$(\bar{L}_o)_{E_A} = 38.1 \log S_A - 2.4 \text{ dB(A)}.$$

For medium trucks:

$$(\bar{L}_o)_{E_{MT}} = 33.9 \log S_{MT} - 16.4 \text{ dB(A)}.$$

For heavy trucks:

$$(\bar{L}_o)_{E_{HT}} = 24.6 \log S_{HT} + 38.5 \text{ dB(A)}.$$

It should be noted that the level for heavy trucks is dependent on vehicular speed at the rate of a 7.4-dB(A) increase per doubling of speed. Previous models always assumed a constant emission level for heavy trucks across the range of speed. This documented speed dependency represents a major improvement in prediction methodology, which greatly reduces overprediction problems at low speeds.

The reference energy mean emission levels shown above are used in almost all cases. When it is likely that a given situation may include a significant percentage of nontypical vehicles (from the perspective of noise-level emissions), site-specific levels may be developed by using prescribed procedures (5). For the DAHE project, the national reference energy mean emission levels were used for automobiles and buses (assumed to be acoustically equivalent to medium trucks) as well as for medium trucks and heavy trucks on the roads that cross the right-of-way.

The parameter α is used in the FHWA model to define ground-cover conditions that may lead to excess attenuation due to absorption. When the ground is determined to be hard (pavement, packed dirt, etc.), no excess attenuation is expected and α is given a value of 0. This causes the distance attenuation factors in Equation 1, $10 \log(D_o/D)^{1+\alpha}$, to become $10 \log(D_o/D)$, which produces a spatial decay rate of 3-dB(A) decrease per doubling of distance. For soft site conditions (grass, vegetation, etc.), α is given a value of 0.5, which causes the distance attenuation factor to become $15 \log(D_o/D)$. This of course produces a spatial decay rate of 4.5-dB(A) decrease per doubling of distance, one-third of which [1.5 dB(A)] is excess attenuation due to absorptive ground cover and two-thirds of which [3.0 dB(A)] is due to distance.

When the ground cover is hard, the actual spatial location of the roadway segment with respect to the receiver is not relevant because only distance is important. However, when the site is soft, knowledge of segment location is critical, since the excess attenuation is dependent on the amount, or width, of absorptive surface present. The parameter $10 \log[\psi_\alpha(\phi_1,\phi_2)/\pi]$ locates the roadway segment with respect to the receiver. Angle ϕ_1 is measured from a perpendicular between the receiver and roadway segment to the left end of the segment, whereas angle ϕ_2 is measured from the same perpendicular to the right end of the segment. When ϕ_1 is measured counterclockwise and ϕ_2 is measured clockwise, the segment is directly in front of the receiver. If both are measured counterclockwise, the segment is to the left of the receiver and, if both are measured clockwise, the segment is to the right of the receiver. If these angles, and therefore the location of the receiver relative to the segment, are known, a simple chart is consulted to obtain an adjustment factor for finite-length roadways at absorbing sites.

As mentioned previously, the most powerful and versatile computer version of the FHWA model is STAMINA 1.0. Although the program will not be discussed in complete detail here, sufficient highlights, for purposes of later evaluation of the DAHE project noise analysis and results, will be presented.

Information is made available to the program in six data blocks: (a) program initialization parameters, (b) roadway parameters, (c) barrier parameters, (d) ground-cover parameters, (e) receiver parameters, and (f) α-input parameters.

The program initialization parameters are insignificant in that they are simple information such as input and output units, height adjustments, and so on.

The second data block, roadway parameters, provides data for up to 20 different roadways, each of which may contain up to 10 straight-line segments. For each roadway, the following data must be provided: (a) hourly volume of each vehicle class, (b) hourly speed of each vehicle class, (c) three-dimensional end-point coordinates of each roadway segment, and (d) a reminder that grade adjustments are to be used for heavy trucks.

The third data block concerns the presence of barriers that may break the line-of-sight plane between the receiver and the roadway segment. For each such barrier up to a maximum of 20 (each able to have 10 segments), the following information must be provided: (a) three-dimensional end-point coordinates of each barrier segment and (b) a reminder that the barrier is absorptive or reflective.

Barrier-attenuation calculations are based on actual path-length differences along a series of rays from receiver to roadway sections. This arrayed approach represents a significant improvement over previous models, which typically assumed only one path-length difference. In those cases, that was the maximum path-length difference, which occurs at the perpendicular point between the roadway section and the receiver.

At this point, one of the more-important shortcomings of STAMINA 1.0 must be mentioned. It is commonly known that the presence of a barrier in the vicinity of a highway creates a new source of highway noise at the top of the barrier and therefore may contribute to loss of excess attenuation from a soft site. This is a major reason for the determination of a comprehensive barrier insertion loss rather than a simple barrier attenuation due to Fresnel diffraction. STAMINA 1.0 overcompensates for the loss of excess attenuation by simply ignoring all ground-cover effects for the segment when any break in the line of sight is present. Thus, when a barrier conceivably 1 in high is present in a soft-site situation, STAMINA 1.0 will call the entire site hard and use a 3.0-dB(A) spatial decay rate rather than one of 4.5 dB(A). The shortcomings of such an assumption are obvious.

When no barriers are present, the fourth data block allows for the insertion of up to 10 rectangular soft ground-cover strips into otherwise hard site areas. The necessary information needed for this optional data block are (a) three-dimensional end-point coordinates of each strip, (b) width of the strip, and (c) information whether the strip is high grass, shrubbery, or trees.

The receiver parameters (the fifth data block) define up to 15 specific locations at which the analyst wants to know the highway noise levels. Information necessary for each receiver includes (a) three-dimensional coordinates and (b) criterion level desired.

This desired criterion level is one of the more-powerful features of STAMINA 1.0. It allows the analyst to select an Leq value above which the segment-by-segment contribution is listed for the receiver. This feature (which is demonstrated in detail later in this paper) has proved to be an indispensable tool in barrier design.

The last data block is made up of the so-called α-table. This provides information concerning expected spatial-decay rates between each receiver and each roadway. When a soft site is to be encountered, α is entered as 0.5 and for a hard site, 0.0. As implied above, however, the presence of a break in the line of sight (barrier) between a given receiver and roadway segment always reduces the α-value to 0.0.

Much more-detailed information concerning the FHWA model and STAMINA 1.0 may be found in FHWA publications (1,2).

DAHE PROJECT NOISE ANALYSIS

Consistent with the potentially controversial nature of the project, the basic design goal was to prevent an individual receptor from experiencing an increase of more than 10 dB(A) for an Leq greater than the existing levels. Because the previously purchased right-of-way corridor was so narrow (typically 500 ft wide), there was no possibility of minimizing noise impacts through modifications in horizontal alignment. Similarly, the presence of roads that crossed the corridor--Old Chain Bridge, Magarity, and Idylwood Roads--as well as the required elevations of the termini at VA-123 and I-66 eliminated the possiblity of significantly modifying the vertical alignment for noise-control purposes. Accordingly, the only option that remained was to design a noise-barrier system to meet the goal.

One further constraint on the project was time: Unlike federal-aid highway funds available to the states, funds for direct federal construction are not automatically carried over beyond the end of any given fiscal year. Because Congress had authorized a significant sum for the DAHE construction in FY 1980 (although the funds were later held up in a budget-balancing move by the Carter Administration), FHWA and FAA had to settle on a contract by September 30, 1980, or risk losing a $4 million appropriation. In order to meet that schedule, it was necessary to complete the noise analysis by early summer. Once approval was given to proceed with the noise study, only about three months remained.

The study approach used in the analysis first selected individual receptors or a group of sensitive receptors deemed to have a possibility of showing noise impact. A total of 30 such receptors was eventually identified and studied, which included 29 residences (or clusters of residences) and one school.

Second, existing noise levels were determined. Measurements had been made previously at 10 receptors as part of the draft environmental-impact statement. These data were supplemented by several additional measurements. By using this information, it was then possible to infer an existing noise-level environment at all locations within the project vicinity. Existing daytime Leq values ranged from 56 dB(A) in the area of VA-123 and Hillcrest Drive (northern terminus) down to 46 dB(A) in the area of Pimmit Run and Stream Valley Park (approximately 0.5 mile north of the I-66 interchange).

Once the existing noise levels had been established, maximum criteria were set at each receiver by simply adding 10 dB(A). At this point, the study began use of STAMINA 1.0. The entire project (including cross roads) was separated into 19 different roadway sections. The roadways were separated when either of two conditions prevailed--when traffic volumes changed or when more than 10 segments were required for acoustical representation.

After determination of roadway sections and segment end points, the tedious and labor-intense task of picking the three-dimensional coordinates from 50 scale plans and cross sections (1 in = 50 ft) was performed. This effort required several person days to accomplish and check. Several more days were then needed to insert the data into computer files for use later on the Vanderbilt DEC-10 remote storage-and-retrieval system. Once this data insertion was completed, however, the remaining activities were virtually all analytic.

The first run of STAMINA 1.0 determined the impact of DAHE construction without use of barriers. This run was accomplished as a super run, in which the entire 2-mile project was coded in and executed as a unit twice, once each for two sets of 15 receivers. This approach had the advantage of providing a continuous printout that has consistent numbering of receivers and roadways. However, many needless and expensive calculations were performed internally in the computer since all roadway segments, some thousands of feet away, operated on all receivers.

This super-run concept was discarded early in the barrier analysis phase when problems developed. Because the input that included the barrier data had such a large number of roadway and barrier segments, it was not uncommon for such segments to line up with a receiver, which caused the program to enter a sort of infinite do-loop configuration. When this happened, execution had to be stopped manually and the receiver shifted slightly in position. It proved to be much less trouble and less expensive to

Figure 6. Roadway segment sound-level contributions that exceed the criterion level of 40.0 dB(A).

```
ROADWAY  SEGMENT

  1        1    2    3
         40.6 41.5 42.8
  2        1    2    3
         42.0 41.7 42.2
  3        1    2
         42.8 43.2
  4        1    3    4
         41.7 38.2 35.8
  5        1
         45.8
  6        1
         38.7

RECEIVER             XRC          YRC          ZRC
   2               61350.0      70500.0       366.0      R18 SS OF HUNTING E END

          LE(A)  LEQB(A)   L90     L50     L10     SIGMA
          60.9     0.0     55.1    59.5    63.9     3.4
ROADWAY  SEGMENT

  1        1    2    3
         40.2 41.3 54.0
  2        1    2    3
         40.0 42.4 45.9
  3        1    2
         40.8 46.0
  4        1    2    3    4
         43.4 46.5 54.9 50.9
  5        1
         55.0
  7        1
         40.9

RECEIVER             XRC          YRC          ZRC
   3               61410.0      69833.0       383.0      R12 SE, CH BRIDGE

          LE(A)  LEQB(A)   L90     L50     L10     SIGMA
          61.7     0.0     56.9    60.7    64.5     3.0
```

simply break the project down into five subsections for later barrier analysis. This, in spite of the loss in continuity of the roadway and receiver numbering system, worked well. Use of the comment and title cards in the data file permitted a consistent number system to be maintained.

For those receivers at which impacts exceeded the criterion of a 10-dB(A) increase over existing levels, barriers were inserted designed to provide an effective height of 10 ft. By using these initial barrier results as a guide, heights (actually elevations) and configurations were then modified to close in on the 10-dB(A) criterion at each receiver. These modifications were made with a minimum of effort, usually by changing two or three numbers in a data file and then reexecuting the program.

At this point in the analysis, the barrier configuration to meet the criterion at each receiver had been determined. In order to optimize the design in terms of cost-effectiveness, however, additional analysis was required. This was accomplished in two steps, each of which took full advantage of the versatility found in STAMINA 1.0.

First, a level criterion of 40 dB(A) was called for at each receiver. This resulted in a printing of the contributions of each roadway segment in the run of which the Leq value was within 5 dB(A) of the criterion [35 dB(A) and higher]. As the example in Figure 6 shows, this produces a very detailed picture of barrier performance. For the DAHE project, this picture was visually enhanced by the development of a series of 200 scaled schematic diagrams of each project area that showed the segment-by-segment contributions to the overall Leq at each receiver (Figure 7). By using these diagrams, it is a relatively straightforward task to isolate those segments of a critical nature and those segments on which reductions in barrier size (and cost) would not affect performance.

Once the barrier configuration had been modified and optimized based on the information gleaned from the schematics, the final step in the noise study was accomplished. The optimized barrier configuration was taken as a base-case assumption, and a sensitivity analysis was undertaken. Four additional runs for each receiver were involved. These included changing the base-case barrier elevations by +4, +2, -2, and -4 ft. The output from these runs indicated several areas at which barrier heights could be lowered without significant compromise in the resulting Leq.

One final series of runs was executed by using the ultimately selected system of barrier locations and elevations. This sytem is fully documented as the most cost-effective system that meets the established criterion for the DAHE project of a maximum 10-dB(A) increase over that existing.

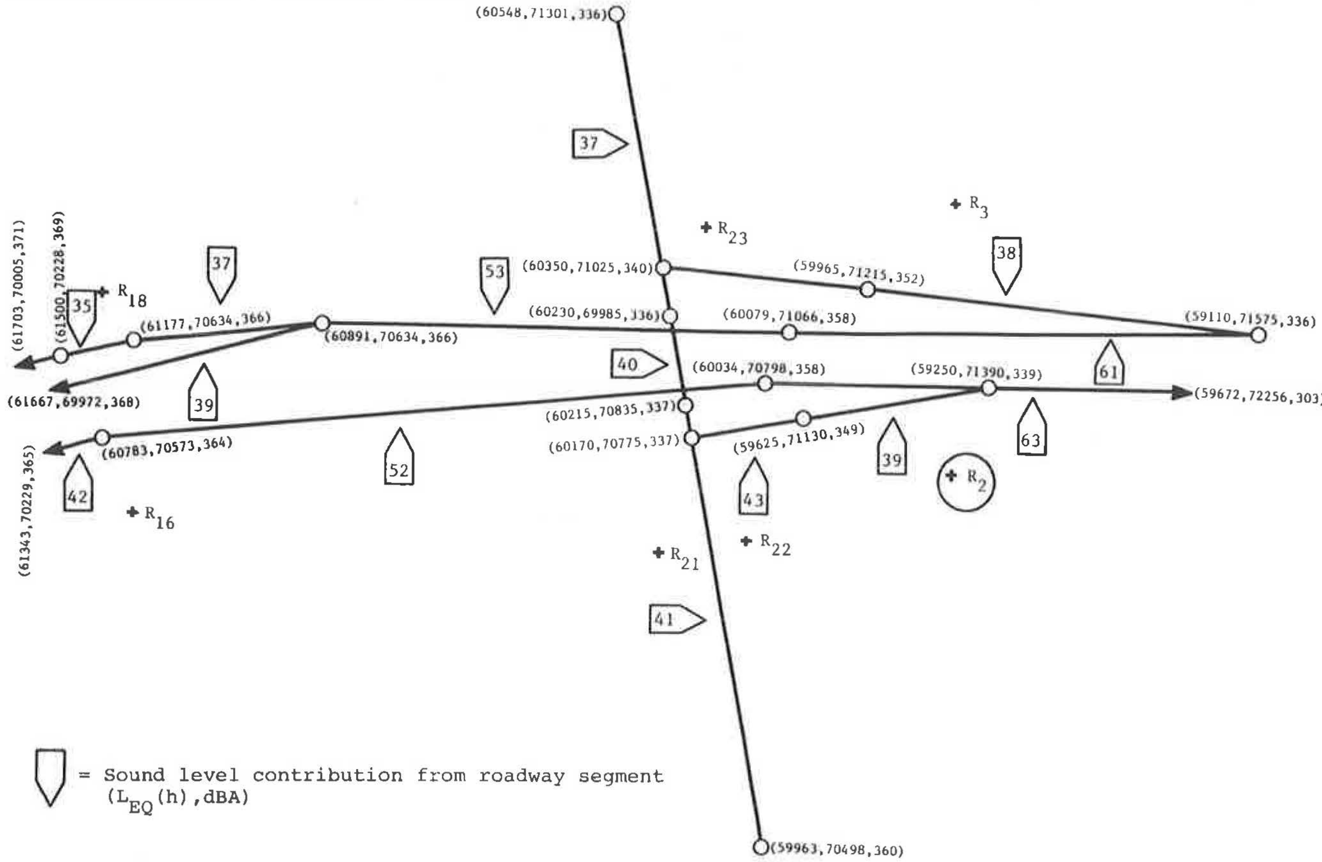
CONCLUSIONS

There will be some noise impacts from the DAHE project. However, due to the incorporation of a noise-barrier system, these impacts will be limited to a maximum of 10 dB(A) over existing Leq values at most receivers. If we consider that eventual implementation of the DAHE project has been public knowledge for two decades and that at no location will resulting noise levels be excessive, adjacent property owners and dwellers should be well satisfied.

As for highway noise-prediction methodologies, this study has shown that the use of a STAMINA 1.0 type of model is essential in barrier design and optimization for most complex situations. Even with its labor-intense coding phase early in the study, STAMINA 1.0 proved to be highly efficient timewise during the period when many runs were required to test a wide variety of barrier configurations. The level-criterion feature proved to be invaluable in this effort.

Even more important, STAMINA 1.0 used an arrayed approach in barrier insertion-loss calculations. This allows for a more-accurate consideration of segments and portions of segments far removed from the perpendicular line that connects the receiver

Figure 7. No-barrier case: R_2 = receiver 2; Leq = 66 dB(A).



and the road. This approach is greatly superior to the cross-sectional approach used by the earlier models.

On the other hand, there is the problem discussed earlier concerning STAMINA 1.0 and its consideration of excess attenuations due to ground cover, or soft site conditions. The assumption that barrier presence, identified by breaking of the line of sight, completely eliminates all excess attenuation is simply incorrect and is in great need of change. This problem required constant monitoring during the course of the DAHE project noise analysis. Upcoming revisions to STAMINA 1.0 that will incorporate the barrier cost reduction (6) will probably resolve this problem.

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