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# Development and Selection of Ammonia Emission Factors for the 1985 NAPAP Emissions Inventory

All ance Technologies Corp., Chapel Hill, NC

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# DEVELOPMENT AND SELECTION OF AMMONIA EMISSION FACTORS FOR THE 1985 NAPAP EMISSIONS INVENTORY

FINAL REPORT

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16. ABSTRACT The report, prepared for the National Acid Precipitation Assessment Program (NAPAP), identifies the most appropriate ammonia (NH3) emission factors available for inclusion in the 1985 NAPAP Emissions Inventory. NH3 emission factors developed for several new NAPAP source categories were compared with factors developed for other inventories. Although many of the NH3 emission factors presented in the report have low quality ratings, those factors determined to be the most accurate for each category were selected for application to the Inventory. Emissions factors and estimates of NH3 emissions are included for human breath, cigarette smoke, and human perspiration but, for reasons discussed, are not included in the Inventory. NH3 emissions from wildlife excrement were investigated; while there is not universal agreement, the report and other NAPAP research conclude that the net contribution to ambient NH3 is zero. The total NH3 emissions included in the Inventory are 1,685,473 tons per year. The most significant NH3 sources, accounting for 83% of the total emissions, were livestock wastes, wastewater treatment, and ammonium nitrate manufacture.

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| Ammonia | Stationary Sources | 07B |
| Emission | Emission Factors | 14G |
| Inventories | | 15E |

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## ABSTRACT

This report was prepared for the National Acid Precipitation Assessment Program (NAPAP) in order to identify the most appropriate ammonia ($NH_3$) emission factors available for inclusion in the 1985 NAPAP Emissions Inventory. Ammonia emission factors developed for several new NAPAP source categories were compared with factors developed for other inventories The factors determined to be the most accurate for each category are presented in this report. Ammonia emissions estimates based on 1985 activity levels and the emission factors presented in this report are summarized. The total $NH_3$ emissions included in the inventory are 1,685,473 tons per year (TPY). Emissions factors and estimates of $NH_3$ emissions are presented for three categories that were not included in the inventory, including emissions from human breath, cigarette smoke and human perspiration. Emission factors and/or activity levels for these categories were not sufficiently reliable to justify their inclusion in the inventory. The issue of ammonia emissions from wildlife excrement is of particular concern. The conclusions of this report and other NAPAP research suggest that the net contribution of wildlife sources to the ambient concentrations of ammonia is zero, and ammonia emission factors equal to zero are presented in this report. The additional NAPAP research suggests that any ammonia emissions from wildlife are reabsorbed into the natural biomass, resulting in a net release to the atmosphere of zero. This position is in conflict with studies which recommend the application of ammonia emission factors for wildlife, thereby suggesting that ammonia releases from wildlife sources may be significant. Clearly, further research is required to resolve this issue. The most significant $NH_3$ emissions sources were livestock wastes, wastewater treatment, and ammonium nitrate manufacture. These sources accounted for more than 83 percent of the total 1985 emissions. Emission factors for these major $NH_3$ sources were assigned low confidence ratings which indicates that a more comprehensive and reliable $NH_3$ emissions database for several significant source categories is needed.



## ACKNOWLEDGEMENTS

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## EXECUTIVE SUMMARY

A major goal of the National Acid Precipitation Assessment Program (NAPAP) is the development of a comprehensive and accurate emissions inventory for pollutants which are believed to play a major role in the chemistry of acid deposition. Ammonia has been identified for inclusion in this inventory.

The purpose of this study was to identify the most appropriate ammonia emission factors available for inclusion in the 1985 NAPAP Emissions Inventory. This involved developing ammonia emission factors for source categories not covered under a previous NAPAP effort and comparing emission factors developed in inventories prepared for NAPAP, the Canadian Environmental Protection Service (EPS), the Electric Power Research Institute (EPRI), and the NASA Langley Research Center.

In this investigation, ammonia emission factors were developed for range animal wastes, wildlife excrement, cigarette smoking, human breath, human perspiration, and wastewater treatment. These categories, in addition to forest fires, were previously identified as potentially large ammonia emissions sources. Relevant data were not available for developing an ammonia emission factor for forest fires.

Though a few of the new ammonia emission factors developed in this study may be considered natural ammonia sources, most natural source ammonia emission factors were developed under a separate NAPAP effort by the National Oceanic and Atmospheric Administration (NOAA).

The newly developed NAPAP factors were rated (A:highest-E:lowest) according to several criteria including the validity of the test methods used, the age of the data, and the representativeness of the database. Appendix A discusses these criteria in detail. All of the new NAPAP factors were assigned the lowest rating of E, except for factors developed for human breath and cigarette smoking which were assigned ratings of D and C, respectively.

Activity levels representative of the 1985 base year were used to estimate total emissions by source category. For wildlife excrement, reliable animal population data were not available.

The comparison of ammonia emission factors developed by NAPAP, EPS, EPRI, and NASA was based on the same criteria which were used to rate the NAPAP factors (see Appendix A). For all source categories, the original NAPAP factors were chosen as the best available for inclusion in the 1985 NAPAP Inventory. Table 1 summarizes the ammonia emission factors selected, their ratings, 1985 activity levels, and 1985 emissions estimates.

Although ammonia emission factors are presented in Table 1 for the categories cigarette smoking, human breath and human perspiration, emissions for these categories were not included in the 1985 NAPAP Emissions Inventory. Ammonia emission factors equal to zero are included in Table 1 for wildlife categories. The decision to exclude emissions for these categories from the inventory was justified by one or more of the following reasons:

- Conflicting research results upon which the emission factors were based contributed significant uncertainty for the application to the NAPAP program
- Activity rate data were either unavailable or unreliable
- Calculated emissions magnitude was too small to be of interest to the NAPAP program

The decision to exclude ammonia emissions from wildlife excrement was based on concerns related to both the sources of data available to develop the emission factors and the uncertainty in estimates of the activity rate data. The conclusions of this study and subsequent NAPAP research suggest that the net contribution of ammonia from wildlife excrement is zero. This position is in conflict with other research results which have recommended the application of emission factors for ammonia from wildlife sources, suggesting that ammonia emissions from wildlife sources may be large.

The emission totals by source category indicate that 48 percent of the 1985 ammonia emissions are due to range animal wastes. The top four categories, range animal wastes, livestock waste management, ammonium nitrate production, and wastewater treatment accounted for 83 percent of the total calculated 1985 ammonia emissions. However, the emission factors for these categories received low confidence ratings. This indicates a need for more accurate and comprehensive ammonia emissions data for many significant ammonia source categories.

Major conclusions of this study are:

1. Comparison of ammonia emission factors developed for NAPAP, EPS, EPRI and NASA resulted in the recommendation of a set of factors for the 1985 NAPAP Inventory. In each category the original NAPAP emission factor was found to represent the best available data.
2. Total ammonia emissions for 1985 can be broken down as follows:
   - range animal wastes (48.0 percent)
   - livestock waste management (23.2 percent)
   - ammonium nitrate production (7.6 percent)
   - wastewater treatment (4.6 percent)
   - other categories (16.6 percent)

3. A more accurate and comprehensive ammonia emissions database should be developed for:

- range animal wastes
- livestock waste management
- wildlife wastes
- wastewater treatment
- forest fires
- human breath and perspiration
- ammonium nitrate manufacture
- mobile sources
- coal and fuel oil combustion
- coke manufacture

TABLE 1. SUMMARY OF AMMONIA EMISSION FACTORS CHOSEN FOR THE 1985 NAPAP EMISSIONS INVENTORY

| Source | Emission factor (lb emitted/ unit)[a] | Activity rate[b] | Units | 1985 Emissions (tons/yr)[c] | Emission factor rating[d] |
|---|---|---|---|---|---|
| **Livestock Wastes** | | | | | |
| Beef cattle feedlots | 13 | $2.3 \times 10^7$ | animals | 151,549 | E |
| Cropland spreading | | | | | |
| beef cattle | 1.7 | $6.5 \times 10^6$ | animals | 5,541 | E |
| dairy cows | 27 | $4.5 \times 10^6$ | animals | 60,736 | E |
| swine | 4.3 | $4.9 \times 10^7$ | animals | 105,457 | E |
| sheep | 1.9 | $1.9 \times 10^6$ | animals | 1,809 | E |
| laying hens | 0.34 | $2.9 \times 10^8$ | animals | 49,839 | E |
| broilers | 0.043 | $5.0 \times 10^8$ | animals | 10,781 | E |
| turkeys | 0.29 | $3.9 \times 10^7$ | animals | 5,579 | E |
| **Combustion Sources** | | | | | |
| Coal | 0.00056 | $8.4 \times 10^8$ | tons coal | 235 | E |
| Fuel oil | 0.8 | $3.4 \times 10^7$ | $10^3$ gallons fuel | 13,563 | E |
| Natural gas | | | | | |
| utility boilers | 3.2 | $3.5 \times 10^6$ | $10^6$ $ft^3$ gas | 5,703 | C |
| industrial boilers | 3.2 | $1.1 \times 10^7$ | $10^6$ $ft^3$ gas | 17,788 | C |
| commercial boilers | 0.49 | $7.3 \times 10^6$ | $10^6$ $ft^3$ gas | 1,800 | C |
| **Mobile Sources** | | | | | |
| Gasoline | | | | | |
| leaded gasoline | 0.42 | $5.3 \times 10^7$ | $10^3$ gallons fuel | 11,168 | D |
| unleaded gasoline | 0.63 | $5.9 \times 10^7$ | $10^3$ gallons fuel | 18,646 | D |
| Diesel | 0.95 | $2.8 \times 10^7$ | $10^3$ gallons fuel | 3,206 | E |

(continued)

TABLE 1. (continued)

| Source | Emission factor (lb emitted/ unit)[a] | Activity rate[b] | Units | 1985 Emissions (tons/yr)[c] | Emission factor rating[d] |
|---|---|---|---|---|---|
| **Ammonium Nitrate Manufacture** | | | | | |
| Neutralizer | | | | | |
| anulator | 18[e] | $1.9\times10^6$ | tons produced | 17,818 | D[f] |
| high density prilling | 18[e] | $2.4\times10^6$ | tons produced | 21,820 | D[f] |
| low density prilling | 18[e] | $9.0\times10^5$ | tons produced | 8,080 | D[f] |
| Solids formation | | | | | |
| evaporation/concentration | | | | | |
| high density | 17[e] | $5.8\times10^5$ | tons produced | 4,905 | D[f] |
| low density | 17[e] | $3.2\times10^5$ | tons produced | 2,726 | D[f] |
| high density prill towers | 57.2 | $2.4\times10^6$ | tons produced | 68,244 | A |
| low density prill towers | 0.26 | $6.4\times10^5$ | tons produced | 83 | A |
| rotary drum granulator | 59.4 | $1.4\times10^5$ | tons produced | 4,011 | D[f] |
| high density prill coolers | 0.04 | $7.2\times10^5$ | to produced | 16 | A |
| low density prill coolers | 0.30 | 0 | tons produced | 0 | A |
| low density prill dryers | 1.6[e] | $1.5\times10^5$ | tons produced | 116 | D[f] |
| granulator coolers | 1.19 | 0 | tons produced | 0 | D[f] |
| **Anhydrous Ammonia Fertilizer** | | | | | |
| Application | 19 | $5.4\times10^6$ | tons fertilizer | 50,988 | C |
| **Petroleum Refineries** | | | | | |
| FCC units | 54 | $1.6\times10^6$ | $10^3$ barrels fresh feed | 42,793 | B |
| TCC units | 6 | $1.7\times10^4$ | $10^3$ barrels fresh feed | 52 | B |
| Reciprocating engine compressors | 0.2 | h | $10^3$ $ft^3$ gas burned | h | B |

(continued)

TABLE 1. (continued)

| Source | Emission factor (lb emitted/ unit)[a] | Activity rate[b] | Units | 1985 Emissions (tons/yr)[c] | Emission factor rating[d] |
|---|---|---|---|---|---|
| **Ammonia Synthesis** | | | | | |
| Carbon dioxide regeneration | 2.0 | $4.9x10^6$ | tons produced | 4,896 | A |
| Condensate stripping | 2.2 | $3.1x10^6$ | tons produced | 3,464 | A |
| **Urea Manufacture** | | | | | |
| Solution formation/ concentration | 18.2 | $4.8x10^6$ | tons produced | 44,122 | A |
| Solids formation | | | | | |
| nonfluidized bed prilling | | | | | |
| agricultural grade | 0.87 | 0 | tons produced | 0 | A |
| fluidized bed prilling | | | | | |
| agricultural grade | 2.9 | $5.2x10^5$ | tons produced | 749 | A |
| feed grade | 4.1 | $1.0x10^4$ | tons produced | 21 | A |
| drum granulation | 2.2 | $2.6x10^6$ | tons produced | 2,897 | A |
| rotary drum cooler | 0.0051 | $4.1x10^5$ | tons produced | 0.1 | A |
| **Coke Manufacture** | | | | | |
| Oven charging | 0.02 | $3.6x10^7$ | tons coal charged | 358 | D |
| Door leaks | 0.06 | $2.1x10^7$ | tons coal charged | 645 | D |
| Coke pushing | 0.1 | $2.7x10^7$ | tons coal charged | 1,364 | D |
| Quenching (contaminated water) | 0.28 | $2.7x10^7$ | tons coal charged | 3,525 | D |
| **Ammonium Phosphate Manufacture** | 0.14 | $8.2x10^6$ | tons $P_2O_5$ produced | 571 | A |

(continued)

TABLE 1. (continued)

| Source | Emission factor (lb emitted/ unit)[a] | Activity rate[b] | Units | 1985 Emissions (tons/yr)[c] | Emission factor rating[d] |
|---|---|---|---|---|---|
| **Range Animal Excrement** | | | | | |
| Beef cattle | 44.4 | $2.6x10^{6}$ | unconfined pop | 578,890 | E |
| Dairy Cattle | 45.0 | $4.9x10^{6}$ | unconfined pop | 109,725 | E |
| Swine | 39.0 | $4.8x10^{6}$ | unconfined pop | 94,593 | E |
| Sheep | 4.5 | $1.0x10^{7}$ | unconfined pop | 22,606 | E |
| **Wastewater Treatment** | 19.0 | $8.2x10^{6}$ | $10^{6}$ gallons | 77,762 | E |
| **Wildlife Excrement**[g] | | | | | |
| Big Game | | | | | |
| carnivores | 0.0 | h | kg animal | h | E |
| herbivores | 0.0 | h | kg animal | h | E |
| Birds | 0.0 | h | kg animal | h | E |
| **Cigarette Smoking**[i] | 1.8 | $7.5x10^{7}$ | $10^{3}$ smokers | 68 | C |
| **Human Breath**[i] | | | | | |
| Smokers | 9.1 | $7.5x10^{7}$ | $10^{3}$ smokers | 340 | D |
| Non-smokers | 12.0 | $1.5x10^{8}$ | $10^{3}$ non-smokers | 911 | D |
| **Human Perspiration**[i] | 0.55 | $2.3x10^{8}$ | person | 60,000 | E |

[a]All factors chosen were developed by NAPAP unless otherwise indicated.

[b]Activity rates are from the 1985 NAPAP Emission Inventory.

(continued)

**Table 1. (continued)**

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[c]Emissions totals do not include 44,218 tons from minor point source process emissions, area source category 99.

[d]See Appendix A and this report for explanation of ratings. (A is highest, E is lowest)

[e]Emission factor is from mid-point of range reported in *AP-42*.

[f]Rating is lower than that reported in *AP-42* because of the listing of a single factor rather than a range (as in *AP-42*).

[g]Emission factors as high as 1.6 lb/kg animal for carnivores, 0.14 lb/kg animal for herbivores and 1.3 lb/kg animal for birds were developed. These emission factors were based on research results that were not representative of the wilderness environment. Other NAPAP research results based on direct ammonia measurements in the wilderness environment support the zero emission factor assumptions presented in Table 1.

[h] Not available.

[i]Emission factor was developed but the emissions for these categories were not included in the 1985 NAPAP Emissions Inventory due to unreliable activity rates or emission factors, or because the total emissions were insignificant.

## SECTION 1
## INTRODUCTION

In 1980, Congress established the National Acid Precipitation Assessment Program (NAPAP) to coordinate and expand research on problems posed by acid deposition in and around the United States. As a part of this program, the Emissions and Controls Task Group is responsible for the development of a comprehensive emissions inventory including all atmospheric compounds believed to play a significant role in the formation of acid deposition. Ammonia ($NH_3$) has been identified as one such compound.

The purpose of this document is to identify the most appropriate set of $NH_3$ emission factors for inclusion in the 1985 NAPAP Emissions Inventory by developing emission factors for source categories not included under a previous NAPAP effort[1] and by comparing factors developed by NAPAP with those developed for inventories sponsored by the Canadian Environmental Protection Service (EPS),[2] the Electric Power Research Institute (EPRI)[3] and the National Aeronautics and Space Administration (NASA).[4]

The new NAPAP factors that are discussed in this document were considered for application to potentially significant ammonia sources for the 1985 NAPAP Emissions Inventory. The categories include wastewater treatment, range and wild animal excrement, cigarette smoking, forest fires, human breath, and human perspiration. With the exception of the wastewater treatment category, emissions for these new source categories were not included in the inventory because either the emission factors or activity levels were unreliable. These factors were multiplied by activity rates for 1985 to develop estimates of the annual ammonia emissions. The factors were rated on a scale of A through E, with A representing the highest level of confidence in the factor and E the lowest level of confidence. The ratings were based on several criteria including the age of the data, the reliability of test methods used, the size of the database, the representativeness of the database, and the accuracy of information upon which engineering estimates were made. Appendix A describes the methodology used to assign data quality ratings.

All ammonia emission factors presented in this document were compared with factors developed for previous inventories sponsored by EPS, EPRI, and NASA to identify the most accurate set of factors for inclusion in the 1985 NAPAP Emissions Inventory. The criteria used for rating the NAPAP factors were also used to compare factors among the inventories.

Finally, the factors chosen were multiplied by nationwide activity levels for 1985 to develop annual emissions estimates for ammonia source categories.

Ammonia emission factors for wildlife categories were not developed for application to the 1985 NAPAP Emissions Inventory. The conclusions of this and other NAPAP research[5] suggest that the net contribution of natural wildlife to atmospheric ammonia concentrations is zero. Therefore emission factors equal to zero are represented in the summary tables in this report for wildlife categories. The current information relevant to wildlife ammonia emissions is discussed in the text of the report. A high degree of uncertainty is associated with the application of any ammonia emission factors for wildlife categories. The conclusions of this study suggest that the net contribution of ammonia to the ambient air from wildlife excrement is zero. This position conflicts with the results of other studies which suggest that ammonia emissions from wildlife sources may be large.

# SECTION 2
# AMMONIA EMISSIONS

## INTRODUCTION

Ammonia emission factors have been developed previously for use by NAPAP[1]. Emission factors were not available, however, for a number of potentially important categories. In this section, ammonia emission factors are presented for the following natural and anthropogenic sources: range animal excrement; wildlife excrement; forest fires; cigarette smoking; human breath; human perspiration; and wastewater treatment. The emission factors developed are rated on a scale of A through E, with A representing the most reliable rating and E the least reliable. The criteria which were used to evaluate the data quality of the emission factors are discussed in Appendix A. Emissions estimates are also presented for some of these categories, depending on the availability of reliable activity data.

## RANGE ANIMAL EXCREMENT

Approximately 67 percent of all livestock wastes are produced by unconfined animals. Though recently there has been a trend toward confinement, unconfined systems will likely continue to dominate in the beef, dairy cattle and sheep industries.[5]

The nitrogen deposited with livestock manure slurry (a mixture of feces and urine) on ranges and pastureland is subject to ammonia volatilization. The rate of volatilization depends on such variables as the ammonia content of the manure, manure placement, ambient temperature, wind velocity, and the pH of the manure. Other common mechanisms of ammonia loss from livestock manure include nitrification and plant uptake.

Ammonia emissions per acre from range animals largely depend on the stocking rates and dung distributions. Robbins (1978)[6] presented typical stocking rates and animal weights for several livestock categories. He reported average stocking rates of 3.5, 9, 7, and 12 head/acre and average animal weights of 935, 1100, 66, and 440 lbs/animal for beef cattle, dairy cattle, sheep, and swine, respectively. Sweeten and Reddell (1976)[7] presented graphical data relating manurial nitrogen defecated on the soil surface to average animal stocking rates in units of $ft^2/lb$. Typical stocking rates were used to find the number of pounds of nitrogen defecated per acre-year from this graph. The nitrogen excreted was found to be 500, 1200, 95, and 900 lbs N/acre-yr, or 143, 133, 13.6, and 75 lbs N/animal-year for beef cattle, dairy cattle, sheep, and swine, respectively.

Ammonia volatilization losses from range animal manure depend on the $NH_4$-N content of the manure (nitrogen present as ammonium). Westerman et al. (1985)[8] collected data on manure characteristics and reported average $NH_4$-N contents in fresh manure of 32, 3, and 52 as a percent of total nitrogen for beef cattle, dairy cattle, and swine, respectively. Since their $NH_4$-N estimate for dairy cattle manure appeared to be unusually low and was based on only three data points, an estimate of 35 percent $NH_4$-N presented by Overcash et al. (1983)[9] was used instead. This estimate was based on twelve data points. No data were available on the $NH_4$-N content of sheep manure. An average of $NH_4$-N estimates for beef and dairy cattle manure (34 percent) was used for sheep.

Typical ammonia volatilization rates in the range setting are difficult to quantify. However, many studies have been conducted to determine volatilization rates from surface-applied animal manures. Assuming that there is no piling of manure in the range setting, volatilization rates would be similar from range animal manure and surface-spread manure. The no-piling assumption presents a worst-case scenario. However, it appears to be a reasonable assumption, since Sweeten (1976)[7] reported that at the end of a typical animal-year of cattle grazing, more than 80 percent of a pasture would have received no manure, 17 percent would have received one defecation, and only 3 percent of the pasture would have received more than one defecation.

Westerman et al. (1985)[8] gathered data from several studies which measured ammonia volatilization losses from surface-spread animal manures. They reported an average ammonia volatilization loss of 80 percent of the applied $NH_4$-N seven days after application. This average was based primarily on a study by Lauer et al. (1976)[10] in which volatilization losses were estimated from surface-applied dairy manure by periodically measuring the total ammoniacal nitrogen content of manure samples collected from the soil surface. Hoff et al. (1981)[11] reported an 82 percent loss of $NH_4$-N applied with surface-spread swine manure. In estimating volatilization losses as a percent of $NH_4$-N applied, 80 percent was used for volatilization from cattle and sheep manure and 82 percent for losses from swine manure.

Ammonia emission factors for the various livestock categories were calculated by multiplying nitrogen excreted (lbs/animal-yr) by the $NH_4$-N contents to determine the amount of $NH_4$-N excreted (lbs/animal-yr). The $NH_4$-N excreted was then multiplied by a molecular weight conversion factor, 1.21, to obtain lbs $NH_3$/animal-yr. Finally, the emission factors were calculated by multiplying ammonia excreted by the percent volatilization.

To calculate total ammonia volatilization, the emission factors were multiplied by unconfined animal populations. Unconfined populations were obtained by multiplying total animal populations obtained from the 1982 Census of Agriculture, by the percent of animals unconfined, presented by Robbins (1978)[6] as 80, 52, 84, and 9 percent for beef cattle, dairy cattle, sheep, and swine respectively. Total 1985 ammonia emissions from range animals were 805,821 tons.

An E rating was assigned to the emission factors for range animal excrement, since no database was available to specifically quantify ammonia emissions from range animal wastes, and it was necessary to make many assumptions to derive the factors.

**WILDLIFE EXCREMENT**

Separate ammonia emission factors were developed for carnivores, herbivores, and birds because of differences in diet and manure characteristics among wildlife species. The emission factors for wildlife excrement developed in this study were based on research results conducted on animals in confined settings and were not representative of conditions in wilderness environments. Additional NAPAP research representative of natural wilderness conditions suggests that the net contribution of ammonia from wildlife is zero.[5] Therefore, emission factors equal to zero are included in the summary tables in this report. Data from Golley et al. (1965)[12] were used to estimate ammonia emissions from carnivore excrement. In this study, feces and urine production were measured from eight bobcats in a laboratory. The bobcats were fed on diets of either chicken, rabbit, or deer meat.

Average feces production for the bobcats was 25 g/day. Since the average weight of the bobcats was 6.5 kg, the manure production was 3.1 lbs/kg animal-year. Nitrogen constitutes approximately 3.7 percent of animal manure.[12] Assuming that livestock wastes and carnivore wastes have similar $NH_4$-N contents, about 40 percent of the total nitrogen excreted would be in the form of $NH_4$-N.[7] Thus, approximately 0.05 lbs $NH_4$-N or 0.06 lbs $NH_3$ were excreted per kg animal-year.

The average bobcat urine production was 238 ml/day. Based on urea concentration of 120 g/l urine and an ammonia concentration of 68 g $NH_3$/l urine, the average ammonia produced in the urine of the bobcats was 16 g/bobcat-day or 2.0 lbs $NH_3$/kg animal-year.

The combined ammonia contents of the feces and urine give an ammonia content of the manure slurry (a mixture of feces and urine) of 2.1 lbs $NH_3$/kg animal-year. Given this estimate, the average volatilization rate from surface-spread manure slurry of 80 percent presented by Westerman et al. (1984)[7] was applied to estimate volatilization from carnivore slurry, which yielded the emission factor of 1.6 lbs $NH_3$/kg animal-year for excrement from carnivorous wildlife.

The emission factor for excrement produced by herbivorous wildlife was derived from data for livestock wastes, since domestic livestock have a vegetarian diet. Data presented by Westerman et al. (1984)[7] suggest that the average ammonia production in manure slurry from dairy cattle, beef cattle, and swine is 0.17, 0.12, and 0.25 lbs/kg animal-year. Assuming an average ammonia volatilization rate of 80 percent for surface-spread manure slurry[7], the emission factor for herbivorous wildlife is 0.14 lbs $NH_3$/kg animal-year.[3]

Data on the characteristics of poultry manure were used to derive a separate ammonia emission factor for wild birds. Loehr (1968)[13] reported an average manure production for poultry of 0.0062 $ft^3$/day and an average manure density of 60 lbs/$ft^3$ for fresh manure mixed with urine. Therefore, the average manure production was 0.37 lbs manure/day with an average nitrogen content of 5.4 percent. Westerman et al. (1984)[7] presented an average of 33 percent $NH_4$-N content based on total nitrogen for fresh poultry manure mixed with urine. Thus, 0.0066 lbs $NH_4$-N

TABLE 2-1. EMISSION FACTORS AND TOTAL 1980 AMMONIA EMISSIONS FOR BIG GAME EXCREMENT

| Animal | Emission factor (lbs NH3/kg animal-yr) | Avg. wt.[a] (kg) | Population[b] | Potential Emissions (tons/yr) |
|---|---|---|---|---|
| Antelope | 0.14 | 45 | 234,000 | 737 |
| Barbary Sheep | 0.14 | NA | 500 | NA |
| Bear | 1.6 | NA | 37,100 | NA |
| Bighorn Sheep | 0.14 | 120 | 16,100 | 152 |
| Buffalo | 0.14 | NA | 800 | NA |
| Caribou | 0.14 | 95 | 250,000 | 1,660 |
| Deer | 0.14 | 75 | 1,230,000 | 6,460 |
| Elk | 0.14 | 270 | 70,100 | 1,320 |
| Wild Boar | 1.6 | NA | 8,300 | NA |
| Moose | 0.14 | 400 | 87,900 | 2,460 |
| Mountain Goat | 0.14 | NA | 5,200 | NA |

[a]Reference 3.

[b]Reference 19.

are excreted per bird each day. Assuming an 80 percent volatilization rate[7], the emission factor for bird manure is 2.35 lbs $NH_3$/bird-year, or 1.3 lbs $NH_3$/kg bird-year.

In order to calculate ammonia emissions, average weights and populations are needed for each wildlife species. Table 2-1 presents total emission estimates for big game animals by wildlife type, where sufficient data were available. Due to the lack of reliable wildlife population data and the uncertainties associated with the emission factors, $NH_3$ emissions from wildlife were not included in the 1985 NAPAP Emissions Inventory. Further NAPAP research suggests that ammonia emission in the wilderness setting are reabsorbed into the natural biomass, resulting in a net release of ammonia to the atmosphere of zero.[5] If the ammonia emissions are largely reabsorbed into the biomass in the natural setting, then regardless of the emission factor or emission rate, the net release of ammonia emissions to the atmosphere would approach zero. The decision to exclude wildlife ammonia emissions from the 1985 NAPAP Emissions Inventory is in conflict with studies that present emissions factors for application, thereby suggesting that ammonia emissions from wildlife may be significant.

## FOREST FIRES

Ammonia emissions from forest fires have been considered negligible in most emissions inventories. Although the emission factor is small, the total emissions from this source may be significant due to the large amount of forest land that burns each year.

Reliable information on ammonia emissions could not be located for this category. A few emissions inventories, including that prepared for EPS, have presented a factor of 0.3 lbs $NH_3$/ton wood burned for ammonia emissions from forest fires. The rationale for the selection of this factor was an inventory by Wholers and Bell (1956)[14].

Since no verifiable emission factor could be located for ammonia from forest fires, this study does not present one and does not recommend a factor for the 1985 NAPAP Emission Inventory. Rather, it is recommended that reliable data be developed for ammonia emissions from this source.

## CIGARETTE SMOKING

Cigarette smoke results from the incomplete combustion of tobacco and consists mainly of nitrogen, oxygen, carbon dioxide, carbon monoxide, hydrogen, argon, and methane.[15] Sloan and Morie (1974)[16] measured ammonia in tobacco smoke using an ammonia electrode. Cigarettes were smoked by a one-port, syringe-type smoking machine adjusted to operate at one 35-ml, two-second puff per minute. To measure ammonia, an Orion Model 95-10 ammonia electrode was used in conjunction with the Orion Model 407 specific-ion meter.

Two domestic cigarette brands (one with a filter and one without a filter), one European brand (dark tobacco), and two non-commercial types (burley tobacco and flue-cured tobacco) were used in the study. Seven analyses were performed on each cigarette type. The average ammonia content of the smoke from the various cigarettes was 81.8 ug $NH_3$/cigarette.

Newsome et al. (1982)[15] measured the content of several compounds in cigarette smoke. A simple smoking machine was used which replicated normal human puff volumes of 40 ml and appropriate velocity distributions during the two-second puff durations. Ammoniacal compounds in the smoke were determined by the Nessler procedure. This method did not distinguish between ammonium compounds and free ammonia. The experiment showed average ammonia contents of 12, 13, and 7.6 ug/40 ml puff for cigarettes with no filter, acetate filters, and acetate adsorbent filters, respectively. The average ammonia content of smoke from these cigarettes was 11 ug $NH_3$/puff. Assuming an average of 11 puffs per cigarette, the resulting factor is 121 ug $NH_3$/cigarette. The overall ammonia emission factor was taken as an average over both studies, or 100 ug $NH_3$/cigarette.

Total ammonia emissions from cigarette smoking in 1980 were calculated using statistical data from a national health survey.[17] A total population of 160,798 was sampled, of which 52,442 or 33 percent were smokers. Therefore, of the total population of the United States in 1980 (226,546,000), approximately 74,760,180 persons were smokers. The study reported an average of 22 cigarettes smoked per person each day or 8030 cigarettes per year. Thus, approximately 1.3 X $10^5$ lbs $NH_3$ or 66 tons were emitted from cigarette smoke in 1980. Since the total emissions of ammonia from cigarette smoking based on 1980 population data are insignificant, estimates were not included in the 1985 NAPAP Emissions Inventory.

The ammonia emission factor for cigarette smoke was based on current data with reliable test methods. Since the database was small, a rating of C was assigned to this factor.

## HUMAN BREATH

Ammonia is produced by the human body as a metabolic end product. A portion of this ammonia is exhaled through respiration.

Nefedov et al. (1969)[18] studied the content of contaminants in the human expired air of 10 smokers and 11 non-smokers. Ammonia and amino compounds were determined by the colorimetric test with Nessler's reagent. The average ammonia content of expired air was 0.56 $mg/m^3$ for smokers and 0.76 $mg/m^3$ for non-smokers. Nefedov also reported an average of 20 $m^3$/day air expired per person Thus, ammonia emission factors for human breath were calculated as 9.1 lbs $NH_3$/1000 person-year for smokers and 12.0 lbs $NH_3$/1000 person-year for non-smokers.

To estimate total ammonia emissions from human breath, 1980 population estimates for smokers and non-smokers in the United States were multiplied by the factors derived. In 1980, a total population of 226,546,000 was reported, with 33 percent or 74,760,180 estimated as smokers and 151,785,820 as non-smokers.[17] Therefore, total 1980 ammonia emissions were 340 tons/year for smokers, 911 tons/year for non-smokers and 1250 tons/year for the entire U.S. population.

The factors developed for human breath were given a D rating. Although reliable test methods were used, the database was small and the test used by Nefedov et al. (1969)[18] did not distinguish between ammonia and amino compounds. Since the reliability of the emission factor for human breath is low and total emissions based on 1980 population are insignificant, emissions from human breath were not included in the 1985 NAPAP Emissions Inventory.

## HUMAN PERSPIRATION

Part of the ammonia produced by the human body as a metabolic product is emitted to the atmosphere as perspiration. Altman and Dittmer (1968)[19] reported that 24.5 g urea are typically produced each day by the human body (assuming a body weight of 70 kg). Approximately 5 percent of this is released through perspiration as ammonia.[20] Thus, the emission factor for human perspiration was calculated as 1.5 lbs $NH_3$/1000 persons-day or 0.55 lbs $NH_3$/person-year.

This factor was multiplied by the total U.S. population for 1980.[17] The total ammonia emissions due to human sweat in 1980 were estimated at 60,000 tons.

The ammonia emission factor for human perspiration was given a low confidence rating of E because the database was small and the data were difficult to verify. Since the ammonia emission factor for ammonia emissions from human perspiration was highly uncertain, emissions for this category were not included in the 1985 NAPAP Emissions Inventory.

## WASTEWATER TREATMENT

Ammonia volatilization rates from publicly-owned treatment works (POTWs) are difficult to quantify accurately. The highly variable nature of the physical/chemical composition of wastewater, the variety of treatment processes available, and the mode/efficiency of selected operations are important variables affecting the fate of free ammonia in wastewater. Various treatment alternatives can also promote several different $NH_3$ removal mechanisms simultaneously. Without detailed information describing the treatment processes and specific operational parameters, estimation of the relative importance of the competing $NH_3$-N removal mechanisms involved during wastewater treatment operations, such as nitrification, bacterial assimilation, adsorption, and volatilization, must be based on engineering judgment.

Evaluation of the ammonia emission potential from POTWs began with a review of the 1984 Needs Survey data collected by the EPA Office of Municipal Pollution Control.[21] Influent and effluent ammonia concentrations for over 850 wastewater treatment facilities nationwide are included in this survey. The mean influent $NH_3$-N removal efficiency derived from the data is approximately 75 percent. This level of $NH_3$-N removal correlates well with accepted engineering assessments[22], and is supported by relevant research involving the efficiency of nitrogen removal from wastewater treatment operations.[23]

The concentration of $NH_3$-N present in untreated domestic wastewater of average strength is approximately 25 mg/l.[22] Assuming typical operations and that the facility data used to calculate the 75 percent $NH_3$-N removal efficiency are representative of the more than 15,000 POTWs operating in the United States, approximately 19 mg $NH_3$-N would be removed during wastewater treatment for every liter of influent treated.

Research has shown that the efficiency of air stripping of free ammonia is greatly dependent on the treatment process and operational parameters. For example, results obtained by Lee and Naimie[24] in a 1984 study of ammonia removal mechanisms showed a dependency on pH for air stripping efficiency ranging from over 90 percent at a pH of 10.0 to less than 10 percent at a pH of 7.5. Since the pH of untreated domestic wastewater generally ranges between 7.0 and 8.0, the $NH_3$-N removal rate due to air stripping would be about 10 percent under normal treatment operations. The emission rate for ammonia from POTWs was thus estimated at 10 percent of the amount of $NH_3$-N removed by treatment operations, or 1.9 mg/liter of influent treated.

An emission factor of 1.9 x $10^{5}$ lbs of $NH_3$/gallon of wastewater influent treated was developed by simply manipulating the units of the estimated emission rate from mg/liter to lbs/gallon. To calculate total ammonia emissions from POTWs nationwide, the emission factor was multiplied by the 8.2 x $10^{11}$ gallons of industrial wastewater treated by POTWs in 1984.[21] The resulting total ammonia emissions from POTWs estimated for 1985 were 77,760 tons.

Broad assumptions were necessary to develop an emission factor for wastewater treatment due to the variations in operating procedures and treatment methods employed at different facilities. Thus, an E rating was assigned to the emission factor for POTWs.

## SECTION 3

## COMPARISON OF NAPAP AMMONIA EMISSION FACTORS TO FACTORS DEVELOPED IN OTHER INVENTORIES

In this section, NAPAP ammonia emission factors, which were developed for application to the 1980 NAPAP Emissions Inventory,[1] are compared to factors developed for inventories sponsored by the Canadian Environmental Protection Service (EPS)[2], the Electric Power Research Institute (EPRI)[3], and the NASA Langley Research Center[4] The objective of the comparative analysis was to identify the most appropriate factors for use in the development of the 1985 NAPAP Emissions Inventory.

Table 3-1 summarizes the ammonia emission factors developed by EPRI, NASA, EPS, and NAPAP. For many source categories, there are large discrepancies between the emission factors. The reasons for such large discrepancies include the lack of a good database characterizing ammonia emissions from most sources and the lack of standard methods for measuring atmospheric ammonia. The selection of appropriate emissions factors for application to the 1985 NAPAP Emissions Inventory is based on an objective analysis of the credibility of the information used to develop the emission factors. For some categories the emissions facators were manipulated to be consistent with the format and structure of the 1985 NAPAP Emissions Inventory.

### LIVESTOCK WASTE MANAGEMENT

#### Cropland Spreading of Manure

The EPRI and NASA factors for livestock waste management were consistently higher than the NAPAP factors for each animal type. The NAPAP factors for animal waste, which have recently been revised, did not differ significantly from the factors developed by EPS; however, the two studies used extremely divergent methods to derive their respective factors.

The EPRI factors for livestock waste management used an overall 50 percent volatilization rate based on total nitrogen excreted. Although the 50 percent figure was referenced to several studies in the EPRI report, Adriano et al. (1974)[25] found nitrogen losses ranging from 26 to 46 percent of total nitrogen applied with cattle manure in a greenhouse. Therefore, 50 percent is larger than the highest loss measured. In addition, nitrogen losses measured in this study were not all due to volatilization. Other mechanisms of nitrogen loss such as denitrification and leaching of $NO_3$ would be included in their estimate as well. The 50 percent volatilization rate was also referenced to Giddens and Rao (1975).[26] Review of this study revealed that a volatilization rate of

## TABLE 3-1. COMPARISON OF AMMONIA EMISSION FACTORS

| Source | Emission Factors NASA[a] | EPRI[b] | EPS[c] | NAPAP | Units |
|---|---|---|---|---|---|
| **Livestock Waste Management[d]** | | | | | |
| Beef cattle | 34 | 103 | 18 | 1.7 | lbs/animal |
| Dairy cows | 71 | 88 | 18 | 27 | lbs/animal |
| Swine | 7 | 14 | 1.4 | 4.3 | lbs/animal |
| Sheep | -- | 9 | 1.8 | 1.9 | lbs/animal |
| Laying hens | 0.4 | 0.8 | -- | 0.34 | lbs/animal |
| Broilers | 0.4 | 0.8 | -- | 0.043 | lbs/animal |
| Turkeys | -- | 2.2 | -- | 0.29 | lbs/animal |
| Beef Cattle Feedlots | -- | -- | . | 13.0 | lbs/animal |
| **Combustion Sources** | | | | | |
| Coal | 2 | 1.9 | 2 | 0.00056 | lbs/tons coal |
| Fuel Oil | 1 | 0.97 | 1 | 0.8 | lbs/$10^3$ gallons |
| Natural gas | 0.3 | -- | -- | -- | lbs/$10^6$ $ft^3$ |
| utility boilers | -- | 3.24 | -- | 3.2 | lbs/$10^6$ $ft^3$ |
| industrial boilers | -- | 3.20 | -- | 3.2 | lbs/$10^6$ $ft^3$ |
| commercial boilers | -- | 0.49 | -- | 0.49 | lbs/$10^6$ $ft^3$ |
| Mobile Sources | | | | | |
| leaded gasoline | 2.0 | 0.64 | 2.0 | 0.42 | lbs/$10^3$ gallons |
| unleaded gasoline | -- | 0.64 | 2.0 | 0.63 | lbs/$10^3$ gallons |
| diesel | 2.0 | 0.95 | 2.0 | 0.95 | lbs/$10^3$ gallons |

(continued)

TABLE 3-1. (Continued)

| Source | NASA[a] | EPRI[b] | EPS[c] | NAPAP | Units |
|---|---|---|---|---|---|
| | | Emission Factors | | | |
| **Ammonium Nitrate Manufacture** | | | | | |
| With granulator | -- | 3.8 | -- | -- | lbs/ton |
| With prill tower | -- | 2.0 | -- | -- | lbs/ton |
| Neutralizer | -- | -- | 1.0 | 18[e] | lbs/ton |
| Solids formation | | | | | |
| evaporation/concentration | -- | -- | 1.0 | 17[e] | lbs/ton |
| high density prill towers | -- | -- | 0.4 | 57.2 | lbs/ton |
| low density prill towers | -- | -- | 0.4 | 0.26 | lbs/ton |
| granulators | -- | -- | -- | 59.4 | lbs/ton |
| high density prill coolers | -- | -- | -- | 0.04 | lbs/ton |
| low density prill coolers | -- | -- | -- | 0.30 | lbs/ton |
| low density dryers | -- | -- | -- | 1.6[e] | lbs/ton |
| granulator coolers | -- | -- | -- | 1.19[e] | lbs/ton |
| **Ammonia Synthesis** | -- | 3.2 | -- | -- | |
| Carbon dioxide regeneration | -- | -- | 2.0 | 2.0 | lbs/ton |
| Condensate stripping | -- | -- | -- | 2.2 | lbs/ton |
| Loading and storage | -- | -- | 40 | -- | lbs/ton |

(continued)

TABLE 3-1. (Continued)

| Source | NASA[a] | EPRI[b] | EPS[c] | NAPAP | Units |
|---|---|---|---|---|---|
| | Emission Factors | | | | |
| **Urea Manufacture** | | | | | |
| Solution formation/ | -- | 4.35 | -- | -- | lbs/ton |
| concentration | -- | -- | -- | 18.24 | |
| Solids formation | | | | | |
| nonfluidized bed prilling | | | | | |
| agricultural grade | -- | -- | -- | 0.87 | lbs/ton |
| fluidized bed prilling | | | | | |
| agricultural bed | -- | -- | -- | 2.9 | lbs/ton |
| feed grade | -- | -- | -- | 4.1 | lbs/ton |
| drum granulation | -- | -- | -- | 2.2 | lbs/ton |
| rotary drum cooler | -- | -- | -- | 0.0051 | lbs/ton |
| **Anhydrous Ammonia Fertilizer** | | | | | |
| Application | 20 | -- | 60 | 19 | lbs/ton |
| **Ammonium Phosphate** | | | | | |
| Manufacture | -- | -- | 0.08 | 0.14 | lbs/ton |
| **Petroleum Refineries** | | | | | |
| FCC units | -- | -- | 54 | 54 | lbs/$10^3$ barrels |
| TCC units | -- | -- | 6 | 6 | lbs/$10^3$ barrels |
| Reciprocating engine | | | | | |
| compressors | -- | -- | -- | 0.2 | lbs/$10^3$ $ft^3$ gas |

(continued)

TABLE 3-1. (Continued)

| Source | NASA[a] | EPRI[b] | EPS[c] | NAPAP | Units |
|---|---|---|---|---|---|
| | Emission Factors | | | | |
| **Coke Manufacture** | | | | | |
| Oven charging | -- | -- | 0.02 | 0.02 | lbs/ton |
| Door leaks | -- | -- | 0.06 | 0.06 | lbs/ton |
| Coke pushing | -- | -- | 0.1 | 0.1 | lbs/ton |
| Quenching (contaminated water) | -- | -- | -- | 0.28 | lbs/ton |
| **Range Animal Excrement** | | | | | |
| Beef Cattle | -- | -- | -- | 44 | lbs/animal |
| Dairy Cattle | -- | -- | -- | 45 | lbs/animal |
| Swine | -- | -- | -- | 39 | lbs/animal |
| Sheep | -- | -- | -- | 4.5 | lbs/animal |
| **Wastewater Treatment** | -- | -- | -- | 19 | lbs/10$^6$ gallons |
| **Wildlife Excrement[f]** | | | | | |
| Big Game | | | | | |
| carnivores | -- | -- | 0.41 | 0.0 | lbs/kg animal |
| herbivores | -- | -- | 0.036 | 0.0 | lbs/kg animal |
| Birds | -- | -- | -- | 0.0 | lbs/kg animal |
| **Forest Fires[g]** | -- | -- | 0.3 | -- | lbs/ton wood |
| **Cigarette Smoking[g]** | -- | -- | 100.0 | 100.0 | ug/cigarette |

(continued)

TABLE 3-1. (Continued)

| Source | NASA[a] | EPRI[b] | EPS[c] | NAPAP | Units |
|---|---|---|---|---|---|
| | Emission Factors | | | | |
| **Human Breath[g]** | | 3.5 | -- | -- | lbs/$10^3$ persons |
| Smokers | -- | -- | 9.1 | 9.1 | lbs/$10^3$ persons |
| Non-smokers | -- | -- | 14 | 12 | lbs/$10^3$ persons |
| **Human Perspiration[g]** | -- | 0.55 | -- | 0.55 | lbs/person |

[a]Reference 3.

[b]Reference 2.

[c]Reference 1.

[d]NASA and EPRI emission factors are for all livestock wastes. EPS emission factors are for wastes from feedlots. NAPAP emission factors for cattle feedlots and cropland spreading of wastes are shown separately.

[e]Emission factor for NAPAP is from the midpoint of range reported in *AP-42*.

[f]Emission factors as high as 1.6 lb/kg animal for carnivores, 0.14 lb/kg animal for herbivores and 1.3 lb/kg animal for birds were developed. These emission factors were based on research results that were not representative of the wilderness environment. Other NAPAP research results based on direct ammonia measurements in the wilderness environment support the zero emission factor assumptions presented in Table 1.

[g]Emission factor was developed but emissions for these categories were not included in the 1985 NAPAP Emissions Inventory due to unreliable activity rates or emission factors or because the total emissions were insignificant.

-- No emission factors reported. Industrial sources were accounted for in the NASA inventory although no emission factors were presented.

47.6 percent of the total nitrogen applied was measured for poultry manure only. The basis for the assumption of 50 percent ammonia loss could not be verified.

The EPRI factors also did not consider differences in manurial ammonia contents between livestock categories and did not account for manure injection. Injection of animal manures reduces volatilization losses dramatically and is an increasingly popular method of manure application since it encourages the conservation of applied nutrients.

The factors developed by NASA for livestock waste management were based on an 85 percent volatilization rate and excretion rates presented by Loehr, 1968.[13] These factors did not account for differences in ammonia content between animal types. The volatilization rate used was for surface-applied manure only and did not account for manure applied by injection. Since neither NASA nor EPRI provided for the lower volatilization rates of injected manure, the NASA and EPRI factors may have overestimated ammonia emissions from livestock waste management.

EPS developed factors for cattle, swine, and sheep in feedlots only. Their factor development was based on the assumption that most of the ammonia emitted from animal waste comes from urine rather than feces. They utilized data on average daily urine production for herbivores and carnivores[20,11] and a 10 percent volatilization rate (Healy et al., 1970)[20] to obtain ammonia emission rates.

The omission of the nitrogen in feces from EPS ammonia emission factor calculations leads to an underestimation of ammonia emissions. Numerous studies characterizing livestock wastes have shown that an average of 50 percent of total manurial nitrogen is present as $NH_4$-N.[8] In this form nitrogen may be readily volatilized. Further, depending on the carbon:nitrogen ratio of manure, a fraction of manurial nitrogen may be transformed into N.'-N over time.[9] In addition, the volatilization rate used by EPS (10 percent) appears low since numerous studies designed to measure ammonia volatilization from surface-spread manure slurry report an average of 80 percent volatilization of applied $NH_4$-N.[8] EPS also used one factor for all animal types. This does not account for differences in $NH_4$-N contents in the manure and urine of various livestock types.

The NAPAP ammonia emission factor for cropland spreading of animal manures has been revised to reflect individual $NH_4$-N contents of manure by livestock category. Previously, an average $NH_4$-N content was used over all animal types. The revised factors are more accurate since they are based on separate $NH_4$-N contents of 43, 38, 58, and 73 percent of total nitrogen for dairy cows, beef cattle, swine, and poultry, respectively (Table 3-2). Since the $NH_4$-N content of sheep manure was not available, an average NH4-N content of dairy cow and beef cattle manure (41 percent) was used. The volatilization rates were based on the average of several studies which included data for surface-spread and injected manure, various manure types, and different manure management practices.[8]

TABLE 3-2. AMMONIA CONTENT IN ANIMAL MANURES AS PERCENT OF TOTAL NITROGEN*

| Manure Type | Dairy Cows | Beef Cattle | Swine | Poultry |
|---|---|---|---|---|
| Fresh | 3 | 32 | 52 | 33 |
| Scraped | 24 | 5 | 28 | 58 |
| Slurry | 39 | 38 | 64 | 75 |
| Lagoon | 67 | 71 | 81 | 86 |
| Average* | 43 | 38 | 58 | 73 |

*Percentages were averaged for manure that was scraped, slurried, and held in lagoons.

These factors were also revised for consistency with other NAPAP factors. The factors for cropland spreading of livestock waste which had been previously developed represented $NH_4$-N emitted rather than $NH_3$ emitted. Since all other NAPAP are expressed in terms of $NH_3$ emitted and not in terms of $NH_4$-N, the factors for cropland spreading were multiplied by a molecular weight conversion factor, 1.21, to obtain the revised factors.

Table 3-3 outlines the revised emission factors which were developed for cropland spreading of animal wastes. Data on total manure voided, nitrogen excreted, and nitrogen available for cropland spreading were obtained from Van Dyne and Gilbertson (1970)[27] (Table 3-3). Emission factors were developed by multiplying the nitrogen available for spreading by the $NH_4$-N content of each manure type and by a 59 percent volatilization rate. This result was multiplied by a molecular weight conversion factor and divided by the animal population for 1974[28] to obtain lbs $NH_3$ emitted/animal-year. Annual ammonia emissions were then calculated by multiplying the factors by animal populations for 1980 obtained from the 1982 Census of Agriculture. Revised emission factors and emissions estimates appear in Table 3-3. The total revised ammonia emissions for cropland spreading of animal manures is 520,000 tons/year.

NAPAP emission factors for livestock waste management included factors for cattle feedlots, as well as cropland spreading. NAPAP developed an emission factor for beef cattle feedlots utilizing over 56 data points from studies which measured ammonia emissions at cattle feedlots. Data were obtained from an EPA study[25] and a study conducted at a Colorado feedlot.[27]

Due to the many variables associated with the measurement of ammonia from livestock wastes, several assumptions were necessary to derive ammonia emission factors from livestock wastes for each inventory. The NAPAP factor, however, appears to be the most reliable since it is based on the widest database and considers differences between animal types and application methods. Therefore, the NAPAP factors for livestock waste management are recommended for inclusion in the 1985 NAPAP Emissions Inventory.

TABLE 3-3. REVISED AMMONIA EMISSIONS FOR LIVESTOCK WASTE MANAGEMENT

| Animal | Manure production[a] ($10^3$ tons/yr) | | Manure for spreading[a] ($10^3$ tons/yr) | | Emission factors[b] (lbs $NH_3$/animal-yr) | Animal population[c] (1982) | 1985 Emissions (tons/yr) |
|---|---|---|---|---|---|---|---|
| | Manure | N | Manure | N | | | |
| Cattle | 62,485 | 1,666 | 17,897 | 304 | 1.7 | $6.5 \times 10^6$ | 5,541 |
| Dairy Cow | 25,210 | 814 | 20,358 | 498 | 27 | $4.5 \times 10^6$ | 60,736 |
| Swine | 13,360 | 1,086 | 5,538 | 284 | 4 3 | $4.9 \times 10^7$ | 105,457 |
| Sheep | 3,796 | 147 | 1,700 | 48 | 1.9 | $1.9 \times 10^6$ | 1,809 |
| Laying Hens | 3,374 | 158 | 3,259 | 92 | 0.34 | $2.9 \times 10^8$ | 49,839 |
| Broilers | 2,086 | 136 | 2,434 | 122 | 0.043 | $5 0 \times 10^8$ | 10,781 |
| Turkeys | 1,251 | 76 | 983 | 36 | 0.29 | $3.9 \times 10^7$ | 5,579 |
| TOTAL | 111,562 | 4,083 | 52,169 | 1,384 | | | 239,742 |

[a]Reference 29.

[b]Calculated by multiplying nitrogen available for spreading by (percent of total nitrogen as $NH_4$-N, by 1.21) and by 59 percent (percent of ammonia in manure that volatilizes) and dividing by animal populations for 1974 (Reference 21). For sheep manure, 41 percent (an average $NH_4$-N content over cattle and dairy cow manure) was used.

[c]Figures for cattle, dairy cows, swine, laying hens, and broilers are taken from reference 11. Figures for sheep and turkeys are taken from reference 21.

**Range Animal Excrement**

NAPAP was the only ammonia inventory that included a separate emission factor for range animal excrement (see Section 2). EPRI included range and pasture lands as an emission source based on land use categories. The EPRI factor for pastureland was based on data by Denmead et al. (1976)[29] for ungrazed pasture only. They used the same factor (5.8 kg $NH_3/m^2$-day) for grazed and ungrazed pastures even though one would expect much greater emissions if a pasture were grazed due to manure deposits. The EPRI factor for rangeland was based on an upper limit from a study by Miner (1976)[30] in which ammonia was estimated from several areas at a dairy farm.

The NAPAP factors for range animal excrement (see section 2) were on a per animal basis rather than a per area basis. This approach accounted for all manure and urine produced by range animals. The factors were based on data characterizing nitrogen production, stocking rates, manure distribution, ammonia content, and volatilization rates by animal group. This per animal approach is consistent with the development of factors from other agricultural systems which involve ammonia emissions from manure such as feedlots and land spreading of manures. Therefore, the NAPAP factors for range cattle excrement are recommended for inclusion in the 1985 NAPAP Emissions Inventory.

**Application to the 1985 NAPAP Emission Inventory**

A composite emission factor was developed to represent ammonia emission from livestock waste management practices for application to the 1985 NAPAP Emission Inventory. The composite factors were developed by calculating the average of the emission factors for cropland spreading and range animal excrement, weighted by the percent of the populations that were confined and unconfined. These weighted average factors were applied to the categories for beef cattle, dairy cattle, swine, and sheep.

The distributions of confined and unconfined populations for each of these categories have been presented by Robbins (1978).[6] The resultant emission factors that were applied for livestock waste management are 36.9 lb/animal for beef cattle; 36.4 lb/animal for dairy cattle; 7.4 lb/animal for swine; and 4.1 lb/animal for sheep. These emission factors were then multiplied by total animal production data by state obtained from the 1982 Census of Agriculture to represent 1985 Emissions.

**COAL COMBUSTION**

The NAPAP ammonia emission factor for coal combustion is smaller than those cited by EPS, EPRI, and NASA by a factor of 1000. The EPS and NASA factors are identical (2.0 lbs $NH_3$/ton coal) and were traced to a report by Wholers and Bell (1956).[14] This reference presented no basis for the estimate. An effort was initiated to locate an original data source for this factor; however, the origin of this factor could not be ascertained.

The EPRI factor (1.9 lbs $NH_3$/ton coal) was developed from Wholers and Bell (1956) and from factors of 2.6 and 1.06 lbs $NH_3$/ton coal presented by Sonderlund (1977)[31] and Muzio and Arand (1976)[32], respectively. The Sonderlund factor was obtained from Hill (1945)[33] which was based on a pre-1945 study. The Muzio and Arand factor was based on tests performed on a laboratory scale firetube boiler firing bituminous coal. The study was designed to study the effects of ammonia injection on the release of nitrogen oxides during coal combustion. The factor (1.06 lbs $NH_3$/ton coal) was based on one data point without ammonia injection. Another point in the study with ammonia injection released only 0.03 lbs $NH_3$/ton coal.

The NAPAP factor for ammonia from coal combustion is 0.00056 lbs $NH_3$/ton coal. This factor was based on a full-scale study at a Wisconsin power plant.[34] Bauer and Andren (1985) took six samples from each of two 527-megawatt furnaces fired with bituminous coal. The units consumed 2 x $10^5$ kg dry coal/hour. The NAPAP factor was based on an average emission rate over Unit II only, since Unit I operated with the addition of ammonium carbonate which is not representative of current practices. Additional support for the NAPAP emission factor is afforded by bench-scale evaluation conducted by the US EPA Industrial Environmental Laboratory.[35] The results of these evaluations showed that the combustion of medium volatile bituminous coal formed essentially no $NH_3$, even under extremely fuel-rich conditions.

Selective catalytic reduction is an $NO_x$ reduction process which uses ammonia as a reagent. Thus, most of the ammonia emissions measured from these units would be due to the $NO_x$ control system and not coal combustion itself. Based on this factor for selective catalytic reduction, NAPAP's emission factor for coal combustion (0.00056 lbs $NH_3$/ton coal) appears to be more reasonable than the 2.0 lbs $NH_3$/ton coal reported by EPA, EPRI, and NASA.

Although the NAPAP factor differs greatly from those developed by EPS, EPRI, and NASA, it represents more recent and reliable data. The other factors are based on unverifiable and outdated sources. Therefore, for coal combustion the NAPAP emission factor of 0.00056 lbs $NH_3$/ton coal is recommended for inclusion in the 1985 NAPAP Emissions Inventory. It should be noted, however, that this factor was based on only six data points from a single boiler firing bituminous coal. In order to develop a more representative factor, more data should be generated on ammonia emission from coal combustion.

## FUEL OIL COMBUSTION

The NAPAP, EPS, EPRI, and NASA ammonia emission factors for fuel oil combustion are all in good agreement. Nevertheless, they will be evaluated in order to determine the most reasonable factors.

The EPS and NASA factors (1 lb $NH_3/10^3$ gallons) were traced back to an inventory presented by Wholers and Bell (1956).[14] The original data used to develop this factor could not be located.

The factor developed for EPRI (0.97 lbs $NH_3/10^3$ gallons) was based on an average of factors developed for residual and distillate oils. The EPRI factor for residual oil was based on Wholers and Bell (1956) and on an average of two tests by Muzio and Arand (1976).[37] This study used a 200,000 BTU/hr unit at 2 percent excess air. Their distillate oil factor was derived from Hovey and Risman (1966)[38] who obtained the factors from two studies conducted earlier than 1954.

NAPAP's ammonia emission factor for fuel oil combustion (0.8 lbs $NH_3/10^3$ gallons) was developed from the Muzio and Arand (1976) data used by EPRI.[32] Though this factor was based on only two data points, it is the most reliable since EPS, EPRI, and NASA all based their factors on unverifiable data presented by Wholers and Bell (1956)[14] which were over three decades old. Therefore, NAPAP's emission factor for fuel oil combustion is recommended for inclusion in the 1985 NAPAP Emissions Inventory.

## NATURAL GAS COMBUSTION

For natural gas combustion, NAPAP and EPRI developed identical factors. EPS did not present factors for this category. The NASA factors were based on values reported by the National Academy of Science (1979)[37] which were traced back to studies over three decades old with little information available on the test methods used.

The NAPAP factors for natural gas boilers were developed from a 200,000 BTU/hour laboratory gas combustor.[32] Separate factors were developed for utility, industrial, and commercial boilers. Each factor was based on weighted averages over varying conditions of excess oxygen as recommended by Cass et al.(1982).[38] The factors were based on 55 data points.

The factors developed by NAPAP and EPRI for ammonia from natural gas combustion are recommended for inclusion in the 1985 Emissions Inventory. NASA's factors were based on outdated studies with little information available on the test methods used.

## MOBILE SOURCES

NAPAP and EPRI developed similar emission factors for mobile sources. NASA and EPS developed identical factors.

The EPS factor (2 lbs $NH_3/10^3$ gallons) was based only on vehicles with three-way catalytic converters. This would tend to overestimate ammonia emissions.

The NASA factor (2 lbs $NH_3/10^3$ gallons) was based on studies over three decades old.[37] This factor is suspect due to the changes in design and performance of automobiles over the past few decades.

Both the NAPAP and EPRI ammonia emission factors for mobile sources were based on studies by Henein (1975)[39], Gentel (1973)[40], Harkins and Nicksic (1967)[41], and Cadle and Mulawa (1980)[42]. These studies measured ammonia emissions from vehicles with and without catalytic converters, using leaded, unleaded, and diesel fuels. NAPAP developed separate factors for leaded, unleaded, and diesel fuels by taking averages over these categories. EPRI did the same, but did not use as many data points as did NAPAP. Therefore, EPRI's factor differed slightly from the NAPAP factor for leaded gasoline.

Since the NAPAP factors were developed from the most current and the largest database, the NAPAP ammonia emission factors for mobile sources are recommended for inclusion in the 1985 NAPAP Emissions Inventory. These factors are 0.42, 0.63, and 0.95 lbs $NH_3/10^3$ gallons fuel for leaded, unleaded, and diesel fuels, respectively.

A composite emission factor was calculated for gasoline highway vehicles. The composite emission factor was calculated as an average of the leaded and unleaded gasoline factors weighted by the percentage of each fuel type sold nationwide. The Petroleum Supply Annual 1985 indicates that 35.5 percent of the gasoline sold in 1985 was leaded and 64.5 percent was unleaded. The weighted average emission factor based on this split between leaded and unleaded gasoline is 0.54 lb/$10^3$ gallon. This emission factor was multiplied by the county level gasoline consumption data to estimate ammonia emissions from highway gasoline vehicles. Off highway gasoline vehicles were assumed to use leaded gasoline.

## AMMONIUM NITRATE PRODUCTION

The ammonia emission factors developed by NAPAP, EPS, and EPRI for ammonium nitrate production differ significantly and were developed at varying degrees of specificity. NASA did not present an emission factor for this source category.

EPS developed separate factors for neutralizers, evaporation/ concentration, and prill towers as 1.0, 1.0, and 0.4 lbs $NH_3$/ton respectively. These factors were developed from questionnaires sent to Canadian manufacturing facilities. Their factors do not differentiate between high and low density prill towers. They also did not include factors for granulators, prill coolers, prill dryers, and granulator coolers.

EPRI presented factors of 3.8 lbs/ton and 2.0 lbs/ton for processes with granulators and prill towers, respectively. These factors were based on factors developed in *AP-42* (Supplement 13) (1982)[43] which has since been revised.

NAPAP developed factors of 18, 17, 57.2, 0.26, 50, 0.04, 0.30, 1.6, and 1 for neutralizers, evaporation/concentration, high density prill towers, low density prill towers, granulators, high density prill coolers, low density prill coolers, low density prill dryers, and granulator coolers, respectively. These factors were based on the revised *AP-42* (Supplement 15).[44] Where *AP-42* reported a range, NAPAP used the mid-point. These factors were assigned ratings of A in *AP-42* except for the factor for neutralizers which was rated B. This represents a high level of confidence in the factors.

The NAPAP ammonia emission factors for ammonium nitrate manufacture represent the best available data and, therefore, are recommended for inclusion in the 1985 NAPAP Emissions Inventory.

## AMMONIA SYNTHESIS

Ammonia emission factors for ammonia synthesis were developed by NAPAP, EPS, and EPRI. For carbon dioxide regeneration, NAPAP and EPS developed identical factors. NAPAP developed the only factor for condensate stripping and EPS developed the only factor for loading and storage. EPRI developed one general factor for ammonia synthesis. NASA did not present a factor for this source category.

The EPS factor for carbon dioxide regeneration (2.0 lbs/ton) was based on *AP-42*.[45] The factor for loading and storage (40 lbs $NH_3$/ton) was based on an article which is out of print and could not be located.[46] Since, the validity of the factor for loading and storage could not be verified, it is rated E, representing an uncertain level of confidence.

EPRI presented one general factor for ammonia synthesis (3.2 lbs $NH_3$/ton) which was based on a version of *AP-42* which has since been revised.[47]

The NAPAP emission factors for ammonia synthesis are 2.0 and 2.2 lbs $NH_3$/ton for carbon dioxide regeneration and condensate stripping, respectively. These factors were based on *AP-42*[45] which rated the factors developed at A, representing a high level of confidence in the data.

The factors for ammonia synthesis presented by EPS and NAPAP are recommended for inclusion in the 1985 NAPAP Emissions Inventory, since they represent the best available data.

## UREA MANUFACTURE

NAPAP and EPRI developed ammonia emission factors for urea manufacture. EPRI presented one general factor, while NAPAP developed separate factors for several processes in urea manufacture.

EPRI reported a factor of 4.35 lbs $NH_3$/ton which was obtained from *AP-42* (Supplement 13)[48] which has since been revised.

NAPAP developed factors of 18.24, 0.87, 2.91, 4.14, 2.15, and 0.0051 lbs $NH_3$/ton for solution formation/concentration, nonfluidized bed prilling (agricultural grade), fluidized bed prilling (agricultural grade), feed grade, drum granulation, and rotary drum cooler, respectively. These factors were derived from *AP-42* (1984)[49] and were given the highest confidence rating of A, except for the factor for rotary drum coolers which was given a rating of C.

The NAPAP ammonia emission factors for urea manufacture represent the most up-to-date and accurate data available and are recommended for inclusion in the 1985 NAPAP Emissions Inventory.

## AMMONIUM PHOSPHATE MANUFACTURE

NAPAP and EPS developed similar ammonia emission factors for ammonium phosphate manufacture. EPRI and NASA did not present factors for this category.

EPS reported a factor of 0.08 lbs $NH_3$/ton $P_2O_5$. This factor was based on questionnaires sent to Canadian manufacturing facilities.

NAPAP reported a factor of 0.14 lbs $NH_3$/ton $P_2O_5$ which was based on factors reported in *AP-42*.[50] The factor was based on test data from controlled phosphate fertilizer plants in Florida and was rated A in *AP-42*.

Since the NAPAP data was based on a reliable database and matched closely with data obtained in Canada, the NAPAP ammonia emission factor for ammonium phosphate manufacture is recommended for the 1985 NAPAP Emissions Inventory.

## ANHYDROUS AMMONIA FERTILIZER APPLICATION

NAPAP, EPS, and NASA developed ammonia emission factors for anhydrous ammonia fertilizer application. The NAPAP and NASA factors agree favorably at 19 and 20 lbs $NH_3$/ton, respectively. The EPS factor is much higher (60 lbs $NH_3$/ton).

The EPS factor was based on a 3 percent loss of applied ammonia. The reference for this rate could not be located.

The NAPAP factor was based on a study by Denmead et al.(1977)[51] in which anhydrous ammonia was injected at a rate of 583 lbs nitrogen per acre at an average depth of 4.9 inches. NAPAP rated this factor at C since it represented accurate, current test methods but a small database.

The NAPAP factor, which agrees well with the NASA factor, is recommended for the 1985 NAPAP Emissions inventory. The EPS factor could not be verified and was rejected because it was much greater than the NAPAP and NASA factors.

## PETROLEUM REFINERIES

NAPAP and EPS developed identical ammonia emission factors for Fluid Catalytic Cracking (FCC) units and Thermal Catalytic Cracking (TCC) units of petroleum refineries. The factors were 54 lbs $NH_3/10^3$ barrels for FCC units and 6 lbs $NH_3/10^3$ barrels for TCC units. NASA and EPRI did not present ammonia emission factors for petroleum refineries.

The EPS factors were based on information published by U.S. EPA (1977).[52] The NAPAP factors were taken from *AP-42* [53] where they were assigned a high confidence rating of B. NAPAP also used an *AP-42* factor for reciprocating engine compressors (0.2 lbs $NH_3/10^3$ $ft^3$ gas).

The identical factors developed by EPS and NAPAP for FCC and TCC units and the NAPAP factor for reciprocating engine compressors are recommended for inclusion in the 1985 NAPAP Emissions Inventory.

## COKE MANUFACTURE

NAPAP and EPS developed identical ammonia emission factors for coke manufacture. EPRI and NASA did not include factors for this category in their inventories.

Both NAPAP and EPS derived their factors from *AP-42*.[54] Ammonia emission factors for oven charging, door leaks, and coke pushing are 0.02, 0.06, and 0.1 lbs $NH_3$/ton, respectively. The data for these factors were provided by a Polish report to the United Nations on air pollution from coke plants.[55] NAPAP presented a factor for quenching as well (0.28 lbs $NH_3$/ton). This factor originated from tests conducted at a Polish coke plant and a U.S. Steel plant.[55,56]

Though the factors developed by NAPAP and EPS were based on a limited database, they represent the best factors available and are recommended for inclusion in the 1985 NAPAP Emissions Inventory.

## WILDLIFE EXCREMENT

EPRI and NASA did not develop ammonia emission factors specifically for wildlife excrement. EPS used two factors to characterize all animal waste emissions; 0.41 lbs $NH_3$/kg animal-year for carnivores and 0.036 lbs $NH_3$/kg animal-year for herbivores. As discussed earlier in this section while comparing factors for livestock wastes, the EPS factor assumes that all emissions are derived from urine alone. This assumption ignores a good deal of available nitrogen in the feces that is emitted from the feces/urine mixture. Also, the 10 percent volatilization rate used by EPS appears low, due to the several studies that reported an average of 80 percent volatilization rate from domestic animal manure slurry (a mixture of feces and urine) based on $NH_4$-N applied.[8]

Although NAPAP derived ammonia emission factors for carnivores, herbivores, and birds (see Section 2), these factors were based on assumptions that are not applicable to the wilderness setting. The factor for carnivores (1.6 lbs $NH_3$/kg animal-year) was based on feces and urine production by bobcats measured by Golley et al.(1965)[12] and typical nitrogen and ammonia contents for livestock wastes.[8,9] The factor for herbivore wastes (0.14 lbs $NH_3$/kg animal-year) was based on data for livestock excrement.[8] The emission factor for birds (1.3 lbs $NH_3$/kg bird-year) was derived from data on production and nitrogen content of poultry manure.[13] Section 2 of this report describes NAPAP's development of these factors and the reasons for not using these factors in the 1985 NAPAP Emissions Inventory. The wildlife categories are included in the summary tables in this report with emission factors equal to zero and a footnote to reinforce the position that these categories represent potential sources of ammonia.

It appears that the assumptions made by EPS led to an underestimation of ammonia from livestock wastes for carnivores and herbivores. NAPAP's factors were also based on many assumptions. NAPAP considered emissions from the nitrogen in feces as well as that in urine, while EPS did not. In addition, NAPAP developed a separate factor for bird manure. Reliable data on the population of wildlife were not available and the development of emissions factors relied on the applicaton of data collected in settings other than the natural ecosystem. Additional NAPAP research suggests that any ammonia emissions resulting from wildlife excrement in the natural setting are reabsorbed by the biomass, therefore, resulting in a net release of ammonia from wildlife of zero.[5] For these reasons the ammonia emission factors for wildlife presented in this report are zero and ammonia emissions for wildlife were not included in the inventory.

## FOREST FIRES

Due to a lack of verifiable data, an emission factor for ammonia from forest fires is not recommended for inclusion in the 1985 NAPAP Inventory. The factor presented by EPS was based on an unverifiable source.[14]

## CIGARETTE SMOKING

EPS and NAPAP developed identical ammonia emission factors for cigarette smoking (see Section 2). NASA and EPRI did not present factors for this source category.

EPS and NAPAP utilized data from the same two studies to develop their factors. Sloan and Morie (1974)[16] measured ammonia from cigarette smoke with an ammonia electrode. They conducted seven analyses on each of several types of cigarettes. Newsome et al. (1982)[15] measured ammonia using Nessler's procedure from cigarettes with no filter, acetate filters and acetate adsorbent filters. The average over these studies resulted in a factor of 100 ug/cigarette presented by EPS and NAPAP. Since the emissions of $NH_3$ for this category based on 1980 population data are insignificant, this category was not included in the 1985 NAPAP Emissions Inventory.

## HUMAN BREATH

Ammonia emission factors for human breath were developed by EPRI, EPS, and NAPAP. The EPRI factor (3.5 lbs $NH_3$/1000 person-year) was based on a value reported by Kuppart et al. (1976).[57] This factor did not distinguish between smokers and non-smokers.

NAPAP and EPS both used data from a Russian study in which ammonia was monitored from the breath of 10 smokers and 11 non-smokers.[18] The average ammonia content was 0.56 and 0.76 mg/m$^3$ expired air for smokers and non-smokers, respectively. For non-smokers, the EPS study used an average ammonia content of 0.839 mg $NH_3$/m$^3$ expired air. Apparently, they divided the total ammonia from 11 non-smokers by 10 rather than 11 to obtain an average. Based on an average 20 $m^3$/day air expired per person[18], NAPAP developed factors of 9.1 and 12.0 lbs $NH_3$/1000 person-year for smokers and non-smokers, respectively (see Section 2). These factors represent the best available data; however, since the factors are uncertain and the emissions based on 1980 population data are insignificant this category was not included in the 1985 NAPAP Inventory.

## HUMAN PERSPIRATION

Identical ammonia emission factors (0.55 lbs $NH_3$/person-year) were developed by EPRI and NAPAP for human sweat (see Section 2). This factor was based on a typical urea production presented by Altman and Dittmer (1968)[19] and a 10 percent loss of this urea as ammonia.[20]

This factor was highly uncertain and is not recommended for inclusion in the 1985 NAPAP Emissions Inventory. A larger and more current database sh d be generated for this source category since human perspiration apparently accounts for a good deal of atmospheric ammonia.

## WASTEWATER TREATMENT

NAPAP was the only inventory to develop a factor for wastewater treatment. The NAPAP factor was based on the 1984 Needs Survey, which includes influent and effluent ammonia concentrations for over 850 wastewater treatment facilities nationwide[21] and on research on ammonia stripping from treatment plants (see section 2). The NAPAP factor (19 lbs $NH_3/10^6$ gallons of wastewater treated) was rated E due to the many assumptions needed to derive the factor. However, since this factor was based on the best data available and resulted in an emissions estimate of 77,762 tons for 1984 (see section 2), it is recommended for inclusion in the 1985 NAPAP Emissions Inventory.

## SECTION 4

## CONCLUSIONS AND RECOMMENDATIONS

The development and evaluation of ammonia emission factors published in several inventories has resulted in the recommendation of a set of factors for inclusion in the 1985 NAPAP Inventory. The factors selected were deemed the most appropriate available based on the validity of the test methods used, the age of the data, and the representativeness and size of the database from which the factors were derived (see Appendix A).

Ammonia emission factors were developed for several new NAPAP sources including range animal wastes, cigarette smoking, human breath, human perspiration, and wastewater treatment as described in Sections 2 and 3. Emission factors for range animal excrement and wastewater treatment were recommended for inclusion in the 1985 NAPAP Emissions Inventory. Of the new factors developed, all were given a low confidence rating of E except for human breath and cigarette smoking which were given ratings of D and C, respectively. Appendix A explains the basis for the assignment of emission factor ratings

A valid emission factor for forest fires could not be developed due to a lack of relevant data. However, ammonia is rarely identified as an emission pollutant in forest fire emissions inventories Although the emissions factor would likely be low, total ammonia emissions from forest fires could still be significant because of the vast amount of forest land burned each year. Deriving an accurate factor for forest fires could therefore be important in developing a complete ammonia emissions inventory.

The selection of the best available set of ammonia emission factors for inclusion in the 1985 NAPAP Emissions Inventory was based on a comparison of ammonia emission factors developed for inventories sponsored by NAPAP, EPS, EPRI, and NASA. This comparison was based on the same basic criteria used to rate the NAPAP factors (see Appendix A). After thorough evaluation, the NAPAP factors were determined the most accurate for all source categories. In many instances, the factors developed in the other inventories were close to or identical to the NAPAP factors. In other cases, when the factors developed were widely divergent, the data for the NAPAP factors were found to be the most accurate, current, and representative data available. Table 4-1 summarizes the emission factors chosen, their ratings, and the resulting 1985 emissions estimates. Emission factors are presented for the categories; cigarette smoking, human breath and human perspiration. Emission factors of zero are recommended for wildlife categories. Emissions for these categories were not included in the 1985 NAPAP Emissions inventory however, due to the lack of activity data, high uncertainty in the emissions factors, or because the emissions based on 1980 activity data were insignificant. Information derived from animal studies in confined settings and

## TABLE 4-1. SUMMARY OF AMMONIA EMISSION FACTORS CHOSEN FOR THE 1985 NAPAP EMISSIONS INVENTORY

| Source | Emission factor (lb emitted/ unit)[a] | Activity rate[b] | Units | 1985 Emissions (tons/yr)[c] | Point source SCC[d] | Area source SCC[d] | Emission factor rating[e] |
|---|---|---|---|---|---|---|---|
| **Livestock Wastes** | | | | | | | |
| Beef Cattle Feedlots | 13 | $2.3x10^7$ | animals | 151,549 | 3-02-020-02 | 77 | E |
| Cropland Spreading | | | | | | | |
| beef cattle | 1.7 | $6.5x10^6$ | animals | 5,541 | f | 71 | E |
| dairy cows | 27 | $4.5x10^6$ | animals | 60,736 | f | 72 | E |
| swine | 4.3 | $4.9x10^7$ | animals | 105,457 | f | 73 | E |
| sheep | 1.9 | $1.9x10^6$ | animals | 1,809 | f | 70 | E |
| laying hens | 0.34 | $2.9x10^8$ | animals | 49,839 | f | 75 | E |
| broilers | 0.043 | $5.0x10^8$ | animals | 10,781 | f | 74 | E |
| turkeys | 0.29 | $3.9x10^7$ | animals | 5,579 | f | 69 | E |
| **Combustion Sources** | | | | | | | |
| Coal | 0.00056 | $8.4x10^8$ | tons coal | 235 | g | g | E |
| Fuel Oil | 0.8 | $3.4x10^7$ | $10^3$ gallons fuel | 13,563 | h | h | E |
| Natural Gas | | | | | | | |
| utility boilers | 3.2 | $3.5x10^6$ | $10^6$ $ft^3$ gas | 5,703 | 1-01-006-xx | NA | C |
| industrial boilers | 3.2 | $1.1x10^7$ | $10^6$ $ft^3$ gas | 17,788 | 1-02-006-xx | 18,98 | C |
| commercial boilers | 0.49 | $7.3x10^6$ | $10^6$ $ft^3$ gas | 1,800 | 1-03-006-xx | 5,11 | C |
| **Mobile Sources** | | | | | | | |
| Gasoline | | | | | f | 27-39 | |
| leaded gasoline | 0.42 | $5.3x10^7$ | $10^3$ gallons fuel | 11,168 | f | f | D |
| unleaded gasoline | 0.63 | $5.9x10^7$ | $10^3$ gallons fuel | 18,646 | f | f | D |
| Diesel | 0.95 | $2.8x10^7$ | $10^3$ gallons fuel | 13,206 | f | 40-44 | E |
| **Ammonium Nitrate Manufacture** | | | | | | | |
| Neutralizer | | | | | | | |
| granulator | 18[i] | $1.9x10^6$ | tons produced | 17,818 | 3 01-027-04 | f | D[i] |
| high density prilling | 18[i] | $2.4x10^6$ | tons produced | 21,820 | 3-01-027-11 | f | D[i] |

(continued)

TABLE 4-1. (continued)

| Source | Emission factor (lb emitted/ unit)[a] | Activity rate[b] | Units | 1985 Emissions (tons/yr)[c] | Point source SCC[d] | Area source SCC[d] | Emission factor rating[e] |
|---|---|---|---|---|---|---|---|
| low density prilling | 18' | $9.0x10^5$ | tons produced | 8,080 | 3-01-027-21 | f | D' |
| Solids formation | | | | | | | |
| evaporation/concentration | | | | | | | |
| high density | 17' | $5.8x10^5$ | tons produced | 4,905 | 3-01-027-17 | f | D' |
| low density | 17' | $3.2x10^5$ | tons produced | 2,726 | 3-01-027-27 | f | D' |
| high density prill towers | 57.2 | $2.4x10^6$ | tons produced | 68,244 | 3-01-027-12 | | A |
| low density prill towers | 0.26 | $6.4x10^5$ | tons produced | 83 | 3-01-027-22 | f | A |
| rotary drum granulators | 59.4 | $1.4x10^5$ | tons produced | 4,011 | 3-01-027-07 | f | D' |
| high density prill coolers | 0.04 | $7.2x10^5$ | tons produced | 16 | 3-01-027-14 | f | A |
| low density prill coolers | 0.30 | 0 | tons produced | 0 | 3-02-027-23 | f | A |
| low density prill dryers | 1.6' | $1.5x10^5$ | tons produced | 116 | 3-01-027-25 | f | D' |
| granulator coolers | 1 | 0 | tons produced | 0 | 3-10-027-06 | f | D' |
| **Anhydrous Ammonia Fertilizer Application** | 19 | $5.4x10^6$ | tons fertilizer | 50,988 | f | 76 | C |
| **Petroleum Refineries** | | | | | | | |
| FCC units | 54 | $1.6x10^6$ | $10^3$ barrels | 42,793 | 3-06-002-01 | f | B |
| TCC units | 6 | $1.7x10^4$ | $10^3$ barrels | 52 | 3-06-003-01 | f | B |
| Reciprocating engine compressors | 0.2 | | $10^3$ $ft^3$ gas burned | f | f | f | B |

(continued)

TABLE 4-1. (continued)

| Source | Emission factor (lb emitted/ unit)[a] | Activity rate[b] | Units | 1985 Emissions (tons/yr)[c] | Point source SCC[d] | Area source SCC[e] | Emission factor rating[e] |
|---|---|---|---|---|---|---|---|
| **Ammonia Synthesis** | | | | | | | |
| Carbon dioxide regeneration | 2.0 | $4.9x10^6$ | tons produced | 4,896 | 3-01-003-08 | f | A |
| Condensate stripping | 2.2 | $3.1x10^6$ | tons produced | 3,464 | 3-01-003-09 | f | A |
| Loading and storage | 40 | 0 | tons produced | 0 | 3-01-001-99 | f | E |
| **Urea Manufacture** | | | | | | | |
| Solution formation/ concentration | 18.2 | $4.8x10^6$ | tons produced | 44,122 | 3-01-040-02 | f | A |
| Solids formation | | | | | | | |
| nonfluidized bed | | | | | | | |
| prilling | | | | | | | |
| agricultural grade | 0.87 | 0 | tons produced | 0 | 3-01-040-03 | f | A |
| fluidized bed prilling | | | | | | | |
| agricultural grade | 2.9 | $5.2x10^5$ | tons produced | 749 | 3-01-040-10 | f | A |
| feed grade | 4.1 | $1.0x10^4$ | tons produced | 21 | 3-01-040-11 | f | A |
| drum granulation | 2.2 | $2.6x10^6$ | tons produced | 2,897 | 3-01-040-04 | f | A |
| rotary drum cooler | 0.0051 | $4.1x10^5$ | tons produced | 0.1 | 3-01-040-12 | f | A |
| **Coke Manufacture** | | | | | | | |
| Oven charging | 0.02 | $3.6x10^7$ | tons coal charged | 358 | 3-03-003-02 | f | D |
| Door leaks | 0.06 | $2.1x10^7$ | tons coal charged | 645 | 3-03-003-08 | f | D |
| Coke pushing | 0.1 | $2.7x10^7$ | tons coal charged | 1,364 | 3-03-003-03 | f | D |
| Quenching (contaminated water) | 0.28 | $2.5x10^7$ | tons coal charged | 3,525 | 3-03-003-04 | f | D |
| **Ammonium Phosphate Manufacture** | 0.14 | $8.2x10^6$ | tons $P_2O_5$ produced | 571 | 3-01-030-02 | f | A |

(continued)

TABLE 4-1. (continued)

| Source | Emission factor (lb emitted/unit)[a] | Activity rate[b] | Units | 1985 Emissions (tons/yr)[c] | Point source SCC[d] | Area source SCC[d] | Emission factor rating[e] |
|---|---|---|---|---|---|---|---|
| **Range Animal Excrement** | | | | | | | |
| Beef Cattle | 44.4 | $2.6\times10^{7}$ | unconfined pop | 578,890 | f | 71 | E |
| Dairy Cattle | 45.0 | $4.9\times10^{6}$ | unconfined pop | 109,725 | f | 72 | E |
| Swine | 39.0 | $4.8\times10^{6}$ | unconfined pop | 94,593 | f | 73 | E |
| Sheep | 4.5 | $1.0\times10^{7}$ | unconfined pop | 22,606 | f | 70 | E |
| **Wastewater Treatment** | 19 | $8.2\times10^{6}$ | $10^{6}$ gallons | 77,762 | 5-01-007-01 | 100 | E |
| **Wildlife Excrement**[k] | | | | | | | |
| Big Game | | | | | | | |
| carnivores | 0.0 | f | kg animal | f | f | f | E |
| herbivores | 0.0 | f | kg animal | f | f | f | E |
| Birds | 0.0 | f | kg animal | f | f | f | E |
| **Cigarette Smoking**[l] | 1.8 | $7.5\times10^{7}$ | $10^{3}$ smokers | 68 | f | f | C |
| **Human Breath**[l] | | | | | | | |
| Smokers | 9.1 | $7.5\times10^{7}$ | $10^{3}$ smokers | 340 | f | f | D |
| Non-smokers | 12.0 | $1.5\times10^{8}$ | $10^{3}$ non-smokers | 911 | f | f | D |
| **Human Perspiration**[l] | 0.55 | $2.3\times10^{8}$ | person | 60,000 | f | f | E |

[a]All factors chosen were developed by NAPAP unless otherwise indicated.

[b]Activity rates are from the 1985 NAPAP Emission Inventory.

(continued)

**TABLE 4-1. (continued)**

[c]Emissions totals do not include 44,218 tons from minor point source process emissions; area source category 99.

[d]Refers to SCCs that were in the 1985 NAPAP Emission Inventory.

[e]See Appendix A and this report for ratings.

[f] Not available.

[g]Includes SCCs 1-01-001-xx through 1-01-003-xx, 1-02-001-xx through 1-02-003-xx, 1-03-001-xx through 1-03-003-xx, 1-05-001-02, and 1-05-002-02; and area source categories 14 and 96.

[h]Includes SCCs 1-01-004-xx through 1-01-005xxx, 1-02-004xx through 1-02-005-xx, 1-03-004-xx through 1-03-005xx, 1-05-001-05, and 1-05-002-05; and area source categories 3, 4, 9, 10, 16, 17 and 97.

[i]Emission factor is from mid-point of range reported in *AP-42*.

[j]Rating is lower than that reported in *AP-42* because of the listing of a single factor rather than a range (as in *AP-42*).

[k]Emission factors as high as 1.6 lb/kg animal for carnivores, 0.14 lb/kg animal for herbivores and 1.3 lb/kg for birds were developed. These emission factors were based on research results that were not representative of the wilderness environment. Other NAPAP research results based on direct ammonia measurements in the wilderness environment support the zero emission factor assumptions presented in Table 1.

[l]Emission factors are presented but emissions were not included in the 1985 NAPAP Emissions Inventory.

from studies of domestic animal production, which could be used to represent emission factors for wildlife categories, is discussed in this report. Emission factors based on these studies are not representative of conditions in the wilderness environment, and are, therefore, unreliable for application to wildlife categories. In the case of ammonia emissions from wildlife sources, additional NAPAP research, that is in preparation for publication, suggests that ammonia emissions from wildlife sources are reabsorbed into the biomass in the natural setting. These results suggest that regardless of the emission factors or emission rates the net release of ammonia to the atmosphere is zero. Clearly, further research is needed to resolve the issues related to the potential contributions of wildlife sources to the emissions of ammonia.

Total ammonia emissions for 1985, calculated using the emission factors chosen for the 1985 NAPAP Inventory, are ranked below by source category.

| Source Category | 1985 Emissions (tons) | Percent of Total Calculated Emissions |
|---|---|---|
| Range Animal Excrement | 805,816 | 47.8 |
| Livestock Waste Mngmt. | 391,293 | 23.2 |
| Ammonium Nitrate Man. | 127,826 | 7.6 |
| Wastewater Treatment | 77,762 | 4.6 |
| Anhydrous Ammonia Appl. | 50,988 | 3.0 |
| Urea Manufacture | 47,790 | 2.8 |
| Mobile Sources | 43,020 | 2.6 |
| Petroleum Refining | 42,845 | 2.6 |
| Combustion | 39,090 | 2.3 |
| Ammonia Synthesis | 8,360 | 0.5 |
| Coke Manufacture | 5,894 | 0.3 |
| Ammonium Phosphate Man. | 571 | negligible |
| Minor Point Sources | 44,218 | 2.6 |
| Total | 1,685,473 | 100 |

Forty eight percent of the ammonia emissions calculated for 1980 were due to range animal wastes. The next largest source categories were livestock waste management, ammonium nitrate manufacture, and wastewater treatment. These top four sources contributed 83 percent of the emissions calculated for 1985.

It must be stressed that these ammonia emissions totals and rankings are estimates based largely on unverified test results. Emissions from the largest sources were based on factors with low confidence ratings, and emissions totals for a potentially large source, wildlife excrement, were assumed to be zero. The assumption of zero emissions from wildlife excrement is consistent with other NAPAP research results. The potential ammonia emissions from wildlife excrement in other studies are based on research results which conflict with NAPAP research results. Any estimates of ammonia emissions from wildlife sources are based on unreliable emission factors and activity data.

The low confidence ratings associated with factors for many of the largest ammonia emissions sources illustrate the lack of accurate ammonia emissions data for many significant source categories. For many sources, the estimation of ammonia is complicated by the interaction of several variables affecting emissions. For example, ammonia emissions from livestock waste varies significantly with manure type, management practice, and atmospheric conditions and are, therefore, difficult to quantify.

The development of a complete and accurate ammonia emissions inventory will require the development of a reliable and more comprehensive set of emission factors and activity rate data for the following source categories:

- livestock waste management
- range animal excrement
- wastewater treatment
- forest fires
- wildlife excrement
- human perspiration and breath
- mobile sources
- coal and fuel oil combustion
- coke manufacture

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# APPENDIX A

# CRITERIA FOR ASSESSING EMISSION FACTORS

This appendix describes the criteria that were used to assess the quality of the ammonia emission factors presented in Section 3. The purpose of the ratings is to provide a qualitative indication of the reliability of the emission factors. Criteria used to assess the emission factors are listed below.

## DISCUSSION OF CRITERIA

**Test methods used:** Most emission factors are determined from either source tests, industry surveys, mass balances, or engineering estimates. The accuracy of these methods depends on several different parameters which change from one emission source to another.

- **Source Tests:** In source testing, samples are taken directly from the source emitting the pollutant. Accurate approved test methods should have been used whenever possible. If an unapproved method or an outdated method was used, the quality of the emission factor should be questioned.

- **Industry Survey:** In a survey, EPA submits a series of questions to a plant or site that is emitting the pollutant in question. The plant or site personnel voluntarily fill out and return the questionnaire to the surveyor. To obtain accurate information, the questions must be worded carefully so that the correct and desired information will be given. If consistent results are reported by the participants, the information may be considered accurate. To effectively assess the quality of an emission factor, the survey methodology should be known.

- **Engineering Estimate:** An engineering estimate is based on process information available to the engineer. The engineer makes several assumptions based on his experience and knowledge of the process. Using these assumptions and other available information, he estimates an emission factor. This method of determining an emission factor is generally the most inaccurate. However, with adequate background information, an accurate estimate can frequently be made.

**Size of Database:** The emission factor becomes increasingly accurate as the database from which the factor was determined expands. Emission factors constructed on information from one source have less credibility than those from several sources.

**Database Represents a Good Cross Section of Industry:** An average emission factor should be determined from a cross section of the industry. A good cross section is related to the size of the database. However, a large database does not ensure a good cross section, and an excellent cross section is possible from a small database.

**Age of Data:** Some emission factors quickly lose credibility for the following reasons.

- The sampling and testing methods may have been proven invalid, and as better methods are developed, inherent flaws in previously used methods are discovered.

- Technological innovations occur in most industries on a regular basis. Consequently, the process parameters used when the emission tests were performed may differ significantly from those currently used in the Industry. Control systems may be more efficient, fuel feed and production rates may differ, the composition of pollutants may be significantly different, etc. As a result, the old emission factor may no longer apply.

- New laws and regulations may be passed which would significantly affect the emissions from a source.

## RATING SYSTEM

A rating system, analogous to the *AP-42* system, was developed to grade each emission factor. Due to the variability in the type of information in the reference used to assign emission factors, a good deal of subjective engineering judgment was used in giving each factor a grade.

Emission factors for each process were given a rating of A through E, with the A rating representing the more reliable emission factor and the E rating a less reliable rating.

A qualitative description of each rating is listed below:

### A Rating

- Large database from surveys or source tests on several different studies was used.
- Database covers a cross section of the industry.
- Emissions were measured using currently valid test methods.
- Emission factors were determined by mass balance based on sound measurement.

### B Rating

- Database is fairly large; however, it is not clear that it represents a good cross section of the industry.
- Emission factor was measured using valid test methods at the time the test was performed. However, tests have since been revised.
- Engineering estimate based on sound, accurate information.

### C Rating

- Database consists of a few good sources.
- Data may or may not be representative of the industry.
- Engineering estimates based on accurate information. However, information is not extensive or complete.

### D Rating

- Database is small. If one sample, it was a representative site.
- Database may not be representative of industry.

- Unapproved test methods may have been used.
- Engineering estimates are based on information where accuracy is questionable.

**E Rating**

- Database is small. Results conflict with each other.
- Any sources tested are not representative of the industry.
- Engineering estimates are based on very little reliable information.

The above ratings are referred to throughout section 3 in the discussion of specific emission factors.