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Calculation of Age Distributions in the Nonroad Model: Growth and Scrappage

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Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Introduction

The NONROAD2005 version of the US EPA nonroad engine emission inventory model ("NONROAD") calculates nonroad equipment populations by age (i.e., an age distribution) for given equipment types and scenario years. This calculation is necessary for the model to account for factors which affect nonroad emissions over time as the in-use fleet ages and turns over to newer equipment, including emissions deterioration, new emissions standards, technology changes, and changes in equipment population resulting from sales growth trends. The NONROAD model calculates equipment age distributions for the base year (as given in the equipment population input file) based on estimated engine populations for that year combined with the scrappage function and growth inputs. The model calculates age distributions for future years by stepping through each year between the base and future years; for each year, the model projects equipment populations, scrappage for each model year of equipment still in service, and equipment sales needed to attain the projected population.

Age distribution refers to the fractions of a given equipment's population that are one, two, three, etc., years old in a given target year. The NONROAD model calculates base year equipment age distributions for each horsepower range of each equipment type based on the median life (hours at full load), activity (hours of use per year), load factor, and current growth rate for that equipment, combined with the model's generalized scrappage function. The term "scrappage" as used here means the final scrapping of equipment (permanently retiring it from service), such that it no longer contributes to the emissions or fuel consumption of the fleet

This methodology is an enhancement of the original methodology (see NR-007, 1998)[1], which also used an iterative step-wise approach but failed to properly account for prior growth in the base year age distribution. The new methodology also differs from the most recent model version (Draft NONROAD2004, as documented in NR-007b, 2004)[2], which used a static age distribution for all target years.

Following are descriptions of the NONROAD model calculation methodology for population growth and equipment age distribution, followed by detailed descriptions of the relevant model inputs and a glossary that defines the key terms used. Terms contained in the glossary are italicized the first time they appear in this report subsequent to this introduction.

Methodology

The NONROAD model calculates estimated equipment populations, the *age distribution* of those populations, *annual equipment sales*, and equipment *scrappage*. These calculations are performed for the *base year*, and then for every year from the base year up to, and including, the specified *target year* for the model run. The model uses the *population growth rate* to project equipment populations from the base year, as provided in the population input file, through the target evaluation year. For each projection year the model back-calculates expected equipment sales for each year as the difference between projected total equipment population and population remaining from each prior model year after that projection year's scrappage has been applied.

The scrappage calculation uses a *scrappage curve* to determine the proportion of equipment of a given age (model year) that has been removed from service. This proportion is then multiplied by the initial population of that age (model year) to determine the *accumulated scrappage* for equipment of that age. Subtracting the accumulated scrappage from initial sales yields the population of equipment still in service. With this information, the age distribution of the population is calculated by dividing the population at each age by the total population. The details of each of these calculations are discussed more fully below, and an example calculation is provided in the Appendix.

Base Year Equipment Population

Estimates of the base year equipment populations (fleet totals, by SCC and power range, but not separated by model year) are contained in the NONROAD model's input files. NONROAD2005 uses 2000 as the base year for most diesel equipment, and 1998 for most spark-ignition equipment. The basis for these estimates is discussed at length in technical report NR-006d, "Nonroad Engine Population Estimates".[3]

Population Growth: Growth Rates and Projected Populations

The NONROAD model projects equipment populations in past and future years (before and after the input population base year) by applying a growth rate to the base year equipment population for each equipment type (SCC) and power range. The growth rates for most equipment types are calculated as linear *annual growth rates* in equipment populations, as reported by Power Systems Research (PSR). This approach is discussed more fully in EPA technical report "Nonroad Engine Growth Estimates" (NR-008c).[4] With certain exceptions, such as All Terrain Vehicles (ATV's), the model assumes that the population growth rate, in terms of number of units per year, remains constant for all years before and after the base year.

The growth rates are used to generate the growth index values that are contained in the growth input data file (nation.grw), which is more completely described in the Inputs section below. The model uses linear interpolation between these growth indexes to calculate any index for target years between the input growth index years. For target years prior to the earliest growth index year or after the latest growth index year the model uses linear extrapolation from the two closest growth index inputs. The target year *total equipment population* for each horsepower range of each equipment type is then calculated by multiplying the base year population by the ratio of the target year growth index to the base year growth index.

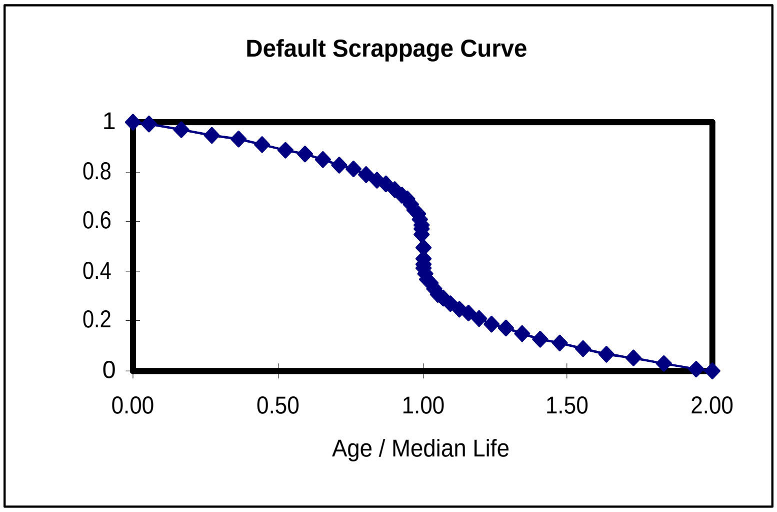
Scrappage

The term "scrappage" as used here means the final scrapping of equipment (permanently retiring it from service), such that it no longer contributes to the emissions or fuel consumption of the fleet. This may be due to aging of the engine or to some other part of the equipment breaking. The determination of the equipment age at the time of scrappage is covered more fully in technical report NR-005c, "Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling."[5]

The NONROAD model uses a *scrappage curve* to determine the proportion of equipment that has been scrapped as a function of equipment age. The scrappage curve is read in from the same data file as the growth data in the "data\growth" directory. The default scrappage curve as shown in Figure 1, and Table 1 comes from the Power Systems Research (PSR) Partslink database.[6] The curve is scaled to the *average lifetime* of the equipment, such that half of the units sold in a given year will be scrapped by the time those units reach the average expected lifetime, and all units will be scrapped by twice the average lifetime. The average lifetime (in years) is calculated as the *median life* (in hours at full load) divided by the *activity level* (hours/year) and the *load factor*.

Average Lifetime (years) = Average Life (hrs) / [Activity (hrs/yr) * Load Factor]

Figure 1 Input Scrappage Curve



Note that in Figure 1, the proportion of equipment that has been scrapped (one minus the fraction surviving) represents the *accumulated scrappage* from the year that the equipment was placed in service.

Table 1. Default Scrappage Curve				
Age/Median Life*	Cumulative Percent Scrapped		Age/Median Life	Cumulative Percent Scrapped
0.0000	0		continued...	
0.0588	1		1.0010	55
0.1694	3		1.0027	57
0.2710	5		1.0058	59
0.3639	7		1.0106	61
0.4486	9		1.0176	63
0.5254	11		1.0270	65
0.5948	13		1.0393	67
0.6570	15		1.0549	69
0.7125	17		1.0741	71
0.7617	19		1.0973	73
0.8049	21		1.1250	75
0.8425	23		1.1575	77
0.8750	25		1.1951	79
0.9027	27		1.2383	81
0.9259	29		1.2875	83
0.9451	31		1.3430	85
0.9607	33		1.4052	87
0.9730	35		1.4746	89
0.9824	37		1.5514	91
0.9894	39		1.6361	93
0.9942	41		1.7290	95
0.9973	43		1.8306	97
0.9990	45		1.9412	99
1.0000	50		2.0000	100
* Age in hours/load factor; Median Life in hours at full load.				

The default scrappage curve used in the NONROAD model is based on a normal distribution of accumulated scrappage versus age. Other distributions could be used; for example, EPA's original proposed 1996 standards for small spark-ignited engines used a Weibull distribution to project fleet turnover. That distribution yields reduced scrappage in the first (newest) few years and increased scrappage in later years than is the case for a normal distribution. The NONROAD model allows a user-specified curve to be substituted for the default curve for any or all equipment types. A user-specified curve can vary the rate of scrappage with age (the shape of the curve) but must conform to the assumption that all units are scrapped within twice the average lifetime.

The *scrappage rate* is defined as the percentage of equipment of a given age removed from service in a given year. The scrappage rate can be derived from the scrappage curve by determining the slope of the scrappage curve at the age in question. Note that for the default scrappage curve, the scrappage rate changes as the equipment age changes: the scrappage rate is low when units are new, reaches a maximum when unit age is equal to the average lifetime, and then declines again for units that are older than the average lifetime.

Age Distribution in the Base Year

To determine the equipment population's actual age distribution as of the base year, one would need to know past equipment sales and scrappage. However, estimates of past equipment sales suffer from missing or incomplete data, are of poor quality, or are based on estimation methods that are incompatible with the methods used to estimate the base year equipment populations used in the NONROAD model. Given these uncertainties, the age distribution in the base year is determined using the relationship between sales growth and population growth, where this relation is a function of average lifetime and the scrappage curve. The methodology involves building up a simulated fleet for each SCC and power range using an arbitrary starting sales value (1000 units/year) and projecting sales out into subsequent years for twice the median life of the engine, taking into account the scrappage that would occur each year. These are just projections of relative sales, not estimates of actual sales. For purposes of this methodology, the last year of this projection is the same as the base population year.

The model growth inputs are given in terms of population growth, rather than sales growth, so the assumed sales growth needs to be consistent with the input population growth at the time of the base year. By performing the sales/scrappage simulation described in the Appendix for a range of sales growth and median life inputs, EPA was able to determine the following relationship between sales growth and population growth:

SalesGrw = PopGrw / { [(-1.4306 x PopGrw) x MedLifeYrs] + (-0.24 x PopGrw) + 1.0 }

where

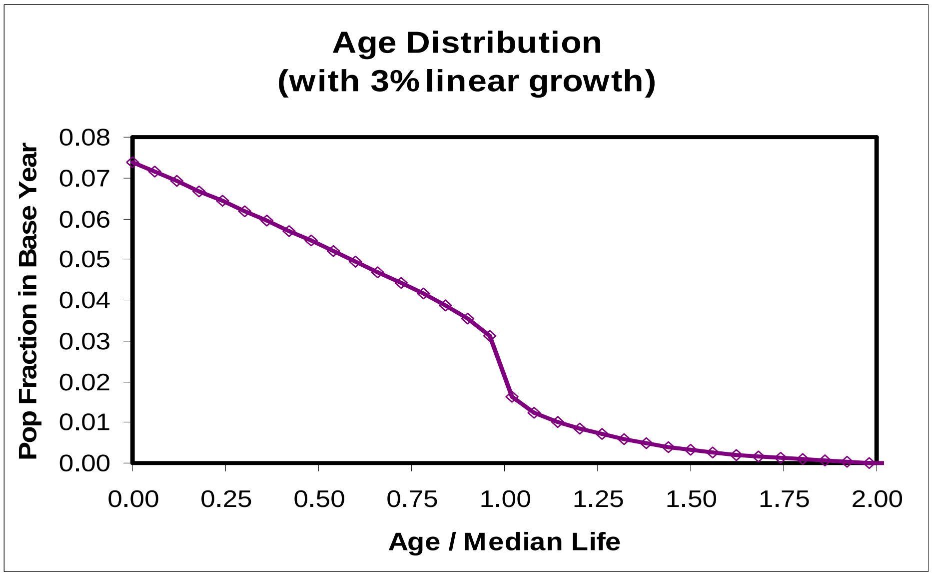
SalesGrw = Growth in engine sales as a percent of the initial year sales. Thus, the same value (percent and absolute number) is applied each year.

PopGrw = Growth in fleet population for a given SCC and power range as determined from the Growth input file (nation.grw), as a percent of the base year population.

MedLifeYrs = Median Expected Life in Years.

Thus, using the model inputs for population growth, median life, and scrappage curve, an initial base year age distribution is generated by calculating the number of engines sold into the fleet in each year minus the number scrapped in each year of that model year's life. Figure 2 shows an example of this initial age distribution for 75 - 100 hp diesel agricultural tractors, which use model inputs of 16.7 years median life (4,667 hrs median life at full load, 475 hrs/year, 0.59 load factor) and 3.0% growth (relative to 1996).

Figure 2 Age Distribution Example (with growth)



Age Distribution in Years Prior to the Base Year

For evaluation years prior to the base population year the model uses the same age distribution as for the base year. The algorithm that is used to project growth and scrappage into future years does not function properly for backcasting, and use of a static age distribution for backcasting is consistent with the way the model has been operating for all prior verions. Thus, this is not considered a significant issue.

Annual Sales and Age Distribution in Future Years

As the model steps through each year from the base year to the target year, it estimates the sales expected to take place during each year. As discussed above, annual sales are determined as the increase in equipment population projected for that year plus the number of units projected to be scrapped that year. I.e., new sales would replace all the equipment lost to scrappage that year, and it would also add enough to increase the equipment population by the amount of growth expected that year.

Sales(Y) = Population(Y) - Population(Y-1) + Scrappage(Y)

where

Sales(Y)	= Equipment sales in given year
Population(Y)	= Equipment population at the end of given year
Population(Y-1)	= Equipment population at the end of prior year
Scrappage(Y)	= Equipment scrapped during given year from all model years

No attempt is made to calculate partial-year scrappage or sales for monthly or seasonal model runs prior to the end of the year; the same population and age distribution are used for any month within the same calendar year.

The age distribution in any given evaluation year for each SCC and power range is simply the number of units of equipment remaining in service from each model year (after applying the sales and scrappage described above) divided by the total remaining from all model years.

Inputs

The calculation of age distributions requires the following data to be supplied to the NONROAD model as input data files. The input filenames are shown in parentheses along with a citation for the NONROAD technical report documenting the data.

Base Year Equipment Population (??.POP, NR-006d)[3]
Median Life at full load (??.POP, NR-005c)[5]
Growth Index inputs (NATION.GRW, NR-008c)[4]
Scrappage Curve (NATION.GRW, this report NR-007c)
Activity (hours/year), (ACTIVITY.DAT, NR-005c)[5]
Load Factor (ACTIVITY.DAT, NR-005c)[5]

Limitations of Methodology

As in previous versions of NONROAD, any type of equipment that is relatively new to the world, or which has experienced substantial increases in sales in recent years, will not have a real world age distribution based simply on median life and scrappage parameters, which is how it is modeled. I.e., the model will show more older units than are actually out there, since they have not been on the market long enough to fill out their full scrappage curve, or because the population is dominated by recent model year sales.

Glossary of Terms

Term	Definition
Accumulated scrappage	The total amount of scrappage that has occurred for equipment of a given model year since its introduction into service (cumulative percent scrapped)
Activity level	The number of hours per year that the equipment in question operates
Age distribution	The function that describes the proportion of surviving (in-service) equipment by age; consists of the full set of model year fractions for a given year
Annual Growth Rate	The linear rate, relative to 1996, at which the equipment population is projected to grow each year in order to reach a specified level
Average lifetime	The age in years at which half of the equipment will have been scrapped (removed from service)
Base year	The year for which the population of a given type of equipment is specified in the population input file
Fraction Surviving (In-service fraction)	The fraction of the engines originally sold in a given year which are still in service (not yet scrapped); the inverse of accumulated scrappage
Cumulative percent scrapped	See Accumulated scrappage
Load factor	The average power level at which the engine operates divided by the maximum available power
Median life at full load	The number of hours that a given type of equipment is expected to survive, if it were operated at full load
Model year	Refers to the year in which equipment was produced. Equipment of the same model year was produced in the same year. To clarify the relationship between age and model year, consider the following example: 1990-model year equipment is (on average) six years old in 1996 and ten years old in 2000.

Glossary of Terms, cont'd

Term	Definition
Model year fraction	The fraction of the total equipment population represented by a given model year at a given point in time
Population growth rate	The rate at which the equipment population increases each year, in number of units per year
Sales growth	The increase (or decrease) in equipment sales each year that is needed to yield the target population growth rate, given specific assumptions of median life, activity, and scrappage.
Scrappage	The final scrapping of equipment (permanently retiring it from service), such that it no longer contributes to the emissions or fuel consumption of the fleet
Scrappage curve	A graphical representation of the scrappage function
Scrappage function	The relationship between equipment age (expressed in terms of the fraction of average lifetime) and the proportion of equipment that has been removed from service, i.e., scrapped
Scrappage rate	The percentage of equipment of a given age removed from service in a given year
Target year	The calendar year for which the NONROAD model's user wishes to estimate emissions and other quantities
Total equipment population	The total number of pieces of equipment in service at a given point in time; the sum of the populations of each model year still in service

References

[1] "Calculation of Age Distributions in the Nonroad Model: Growth and Scrappage," NR-007, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, February 18, 1998.

[2] "Calculation of Age Distributions in the Nonroad Model -- Growth and Scrappage," NR-007b (EPA420-P-04-007), U.S. Environmental Protection Agency, Office of Transportation and Air Quality, April 2004.

[3] "Nonroad Engine Population Estimates," NR-006d, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, December 2005.

[4] "Nonroad Engine Growth Estimates," NR-008c, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, April 2004.

[5] "Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling," NR-005c, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, April 2004.

[6] Power Systems Research, Inc. "Reference Guide, U.S. PartsLink." Edition 6.2 St. Paul, MN.

APPENDIX

Numeric Example of Projected Population Growth and Scrappage

As an example of the growth/scrappage calculations we will consider residential lawn mowers. The basic parameters that the model uses in these calculations are:

Base US Population in 1996:	31,652,672 (3-6 hp bin, from US.POP)
Median Life	47.9 hours at full load (from US.POP)
Activity	25 hours/year (from ACTIVITY.DAT)
Load Factor	0.33 (from ACTIVITY.DAT)
Growth (linear from 1996)	2.25%/yr (1045-1000)/(1998-1996) (from NATION.GRW)
Scrappage Curve	(from ACTIVITY.DAT)

Table A1. Scrappage as Function of Age[a]

Mower Age (yrs)	Fraction of MedLife used	Cumulative Percent scrapped	1-Year Fraction of Original Sales Scrapped[b]	1-Year Fraction of Remains Scrapped[c]
1	0.000	0.0	0.0	0.0
2	0.172	3.0	0.030	0.0300
3	0.344	6.5	0.035	0.0361
4	0.517	10.5	0.040	0.0428
5	0.689	16.0	0.055	0.0615
6	0.861	24.0	0.080	0.0952
7	1.033	66.0	0.420	0.5526
8	1.206	79.5	0.135	0.3971
9	1.378	86.0	0.065	0.3171
10	1.550	90.5	0.045	0.3214
11	1.722	94.5	0.040	0.4211
12	1.895	98.0	0.035	0.6364
13	2.067	100.0	0.020	1.0000

[a] The values in this table are based on the scrappage curve values of Table 1, but are different points on that curve representing one year increments for an engine with a median life of a residential lawnmower per NONROAD inputs.

[b] The portion of the original equipment population that is scrapped in the given year of its life. The sum of these values equals 1.0 (100% of the original equipment is eventually scrapped).

[c] The portion of equipment population surviving at the given age that is scrapped in that year of its life. In the final year of life 100% of the surviving equipment is scrapped, which equals 2.0% of the original population.

Using the methodology described in this report, the age distribution in the base year is calculated as shown in Table A2, using an arbitrary initial "sales" of 1,000 and applying the scrappage from Table A1 along with the sales growth (derived from the input population growth).

In the first year 1,000 units are sold. In the second year 1,028 units are sold, and 30 engines (3.0%) of the first year's sales are scrapped. In the third year, sales grow to 1,056 units, while 3.0% of the second year's sales are scrapped and an additional 35 units (3.5%) of the first year's sales are scrapped. This pattern is followed for as many years as it takes to reach a steady-state point -- i.e., where all of the first year's sales have been scrapped. In this particular case using the median life and activity for lawnmowers that takes 13 years. The first "Pop" column of Table A2 shows the sum of units sold that year plus those remaining in use that year (not yet scrapped) from prior years' sales. The row of most interest here is the final (Year 13) row in which the scrappage curve has been completed and steady-state sales/scrappage has been reached. The age distribution in this year, for the given set of inputs, represents a starting point from which future fleet growth (with scrappage) can be calculated. Thus the ratio of each value in the last row of columns 2 through 13 to the total population (7,819) in that year represents the in-use model year fraction for a model year that many years old. These fractions are shown in the first column of Table A3, which represents the base year age distribution that will serve as the starting point for the growth calculations.

Table A3 shows how the age distribution is calculated for future projection years. Starting from the base year, which was calculated per the prior paragraph, the entries for the next year (Base+1) are calculated as follows. For Mower Age 2, multiply the prior year (Base Year) entry of 0.1706 by the "1-Year Fraction of Remains Scrapped" entry from Table A1 for Mower Age of 2 years (0.03), which equals 0.0051. This is the portion of those engines scrapped that year, so the remaining portion would be 0.1706 - 0.0051 = 0.1655, which shows up as the Base+1 entry for Mower Age 2. This same procedure is followed for all the older mower ages (3 through 12) in the Base+1 column. Finally, the Mower Age 1 entry is computed as the difference between the total fleet population (Base grown by one year) and the sum of all the older model years. I.e., Mower Age 1 fraction = 1.0225 - Sum(0.1655+0.1562+... +0.0027) = 0.1744.

Subsequent growth years (Base+2, Base+3, etc.) are computed the same way, applying the "1-Year Fraction of Remains Scrapped" values from Table A1 to the age distribution fractions of one year to determine the age distribution in the subsequent year.

Table A2 Build-up of Base Year Population by Age from Sales and Scrappage

		6255	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Pop	**Year**	**Remains**	**6429**	**6603**	**6778**	**6952**	**7126**	**7300**	**7475**	**7649**	**7823**	**7997**	**8172**	**8346**
	1	1000												
1028	2	970	1027.9	0	0	0	0	0	0	0	0	0	0	0
2053	3	935	997.0	1055.7	0	0	0	0	0	0	0	0	0	0
3069	4	895	961.0	1024.0	1083.6	0	0	0	0	0	0	0	0	0
4070	5	840	919.9	987.1	1051.1	1111.4	0	0	0	0	0	0	0	0
5039	6	760	863.4	944.9	1013.1	1078.1	1139.3	0	0	0	0	0	0	0
5949	7	340	781.2	886.8	969.8	1039.2	1105.1	1167.1	0	0	0	0	0	0
6449	8	205	349.5	802.3	910.2	994.7	1065.2	1132.1	1195.0	0	0	0	0	0
6820	9	140	210.7	358.9	823.5	933.6	1019.7	1091.3	1159.1	1222.9	0	0	0	0
7129	10	95	143.9	216.4	368.4	844.7	957.0	1044.6	1117.3	1186.2	1250.7	0	0	0
7396	11	55	97.6	147.8	222.1	377.9	865.9	980.4	1069.5	1143.4	1213.2	1278.6	0	0
7625	12	20	56.5	100.3	151.7	227.8	387.4	887.0	1003.8	1094.5	1169.4	1240.2	1306.4	0
7819	**13**	**0**	**20.6**	**58.1**	**102.9**	**155.6**	**233.6**	**396.8**	**908.2**	**1027.2**	**1119.4**	**1195.5**	**1267.2**	**1334.3**

Table A3 Age Distribution with Growth

Mower Age (years)	Fraction of Fleet			
	Base Year	Base+1	Base+2	Base+3
1	0.1706	0.1744	0.1780	0.1816
2	0.1621	0.1655	0.1692	0.1726
3	0.1529	0.1562	0.1595	0.1631
4	0.1432	0.1463	0.1495	0.1527
5	0.1314	0.1344	0.1374	0.1403
6	0.1161	0.1189	0.1216	0.1243
7	0.0507	0.0520	0.0532	0.0544
8	0.0299	0.0306	0.0313	0.0321
9	0.0199	0.0204	0.0209	0.0214
10	0.0132	0.0135	0.0138	0.0142
11	0.0074	0.0076	0.0078	0.0080
12	0.0026	0.0027	0.0028	0.0028
13	0.0000	0.0000	0.0000	0.0000
Total	1.0000	1.0225	1.0450	1.0675