Evolving Adjustments to External (Gamma) Slope Factors for CERCLA Risk and Dose Assessments: The MCNP Years - 16307

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ABSTRACT

To model the external exposure pathway in risk and dose assessments of radioactive contamination at Superfund sites, the U.S. Environmental Protection Agency (EPA) uses slope factors (SFs), also known as risk coefficients, and dose conversion factors (DCFs). Without any adjustment these external radiation exposure pathways effectively assumes that an individual is exposed to a source geometry that is effectively an infinite slab. The concept of an "infinite slab" means that the thickness of the contaminated zone and its aerial extent are so large that it behaves as if it were infinite in its physical dimensions. EPA has been making increasingly complex adjustments to account for the extent of the contamination and its corresponding radiation field to provide more accurate risk and dose assessment modeling when using its calculators.

INTRODUCTION

Prior to 2000, EPA assumed for purposes of estimating the external pathway for risk and dose assessment of radioactive contamination at Superfund sites, the contamination existed over an infinite distance and depth. Then EPA began to issue new guidance to more accurately reflect the gamma radiation fields posed by contamination at Superfund sites. Most recently EPA has begun to make these adjustments using a software program Monte Carlo N-Particle (MCNP).

METHOD AND RESULTS

Initial Area Correction Factors (ACFs) for Soil

In Part 5 of the "Soil Screening Guidance for Radionuclides: Technical Background Document" [1], EPA developed Area Correction Factors (ACFs) for adjusting slope factors for eight site sizes. In this guidance EPA provided recommended ACFs for radionuclides as a function of source area calculated using MicroShield V5.01.1. Since the default source size is 0.5-acre (i.e., 2,000 m^2), the default ACF for default soil screening level risk assessment equations were set at 0.9. The calculations assumed a uniform layer of contamination 15 cm deep with a soil density of 1.6 g/cm^3. A single recommended value was considered suitable for all radionuclides over the range of source areas since EPA's analysis shows that ACFs vary little from one radionuclide to another.

EPA has also provided examples of ACFs for seven radionuclides as a function of source area calculated using MicroShield V5.01. The calculations again assumed a uniform layer of contamination 15 cm deep with a soil density of 1.6 g/cm^3. The guidance recommended that users that have one of the radionuclides from the analysis as a contaminant at their site may use the radionuclide specific ACF that is appropriate for their source area rather than the general value otherwise used for all radionuclides.

Initial Adjustments for Buildings

For the Preliminary Remediation Goals for Radionuclides in Buildings (BPRG) electronic calculator issued on August 29, 2007 [2], EPA made two sets of further enhancements. First, EPA issued external ground plane SFs for 800 radionuclides for assessing contamination that existed only on the surface of walls, floors, or ceiling. This was in addition to the traditional external SFs that assumed an infinite depth. These ground plane slope factors were developed by converting the ground plane external DCFs in Federal Guidance 13. [3]

Second, EPA issued surfaces factors (FSURF) to account for the varying radiation fields inside a contaminated room within a structure. The surfaces factor, in the recommended default and site-specific equations, is based on exposure to 4 walls, the floor and the ceiling in a room. This calculator uses the relationship between the dose rate coefficients for exposures in a contaminated room and dose rate coefficients for an infinite source to calculate a surfaces factor (FSURF). The dose quantity evaluated is the air kerma rate one meter above the floor. The floor, walls and ceiling of the rooms are assumed to be contaminated to the same level. 81 locations in 5 room sizes, ranging from 10 by 10 by 10 feet to 400 by 400 by 40 feet, were modeled to account for the dose contribution from multiple surfaces. The FSURF for the default option was set to the most protective value across the 5 room sizes and 4 receptor positions. In the site-specifc option the user can select from the 5 room sizes and 4 receptor positions: average, center, center wall and corner for each of 800 radionuclides. Further, photon energies of each radioisotope were incorporated into the modeling. The methodology for developing isotope-specific dose rates and the results are discussed in the report “Dose Rates in Contaminated Rooms of Various Sizes” [4]. The results show that only at very low photon energies, is the position of the receptor in the room likely to be relevant. Also shown is that only at very low photon levels is the size of the room likely to be relevant as shown in Figures 1 and 2. The report contains a table of the 16,000 FSURF values used in the BPRG calculator for each radioisotope, room size and receptor position.

Initial Adjustments for Outside Hard Surfaces

For the Preliminary Remediation Goals for Radionuclides in Outdoor Surfaces (SPRG) electronic calculator issued on January 16, 2009[5], EPA made three sets of further enhancements, each of which were made for 800 radionuclides. First, EPA issued external 1 centimetre, 5 centimetre, and 15 centimetre SFs for contamination that had was only as thick as each of those respective amounts. These external SFs were in addition to the ground plane SF first used in the BPRG calculator and the traditional infinite depth SF. These differing centimetre slope factors were developed by converting the centimetre DCFs in Federal Guidance 13.[3].

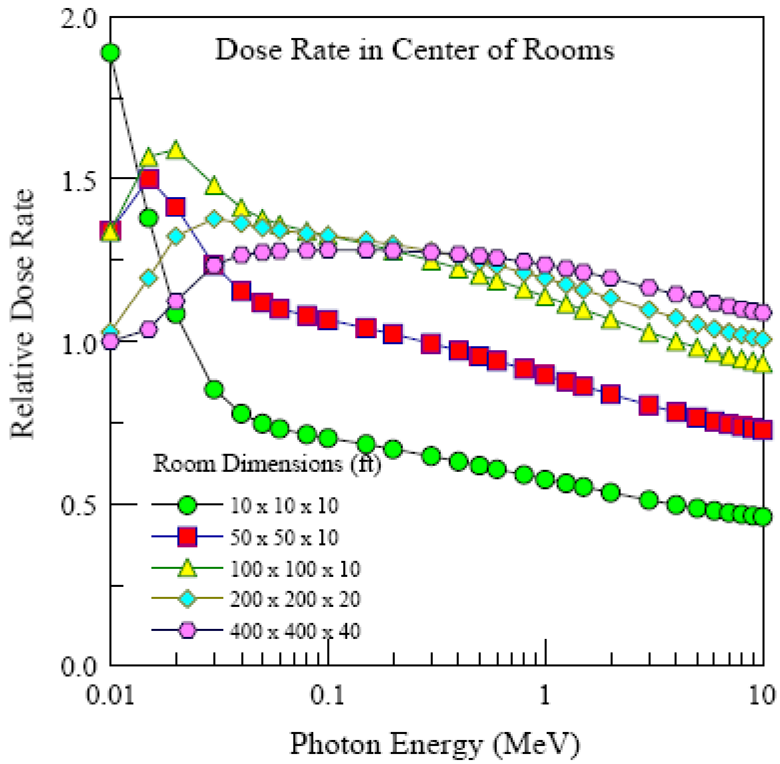

Fig. 1. Relative dose rate in center of rooms of various sizes.

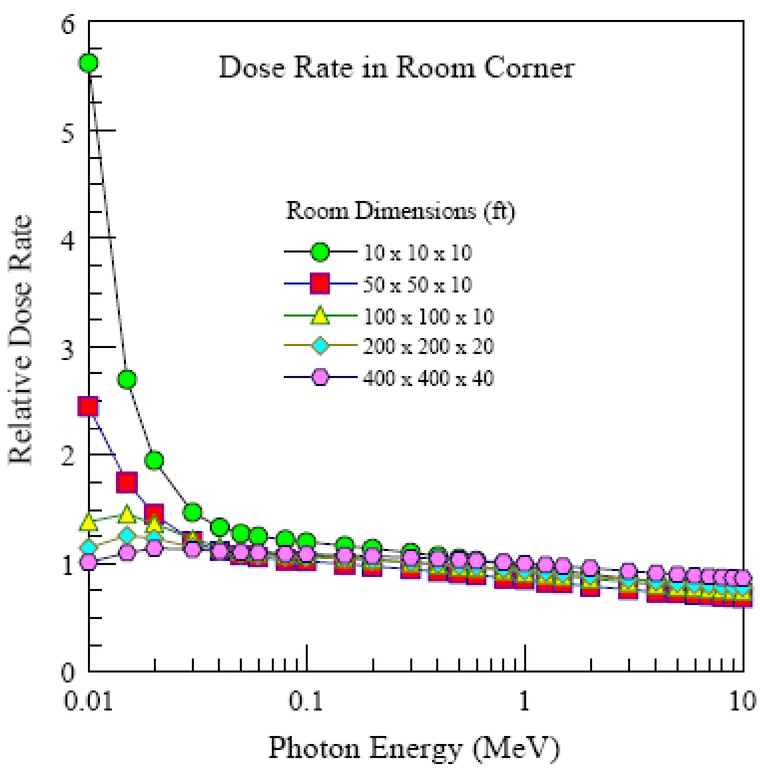

Fig. 2. Relative dose rate in the corner of rooms of various sizes.

Second, in the SPRG calculator EPA issued new FSURF values based on exposure to 2 vertical surfaces (outside building surfaces on either side of a street) and a horizontal surface (road and sidewalk). The SPRG calculator uses the relationship between the dose rate coefficients for exposures in a contaminated outdoor setting and dose rate coefficients for an infinite source to calculate a surfaces factor (FSURF). The dose quantity evaluated is the air kerma rate one meter above the sidewalk. The outdoor surfaces are assumed to be contaminated to the same level. Locations in the midpoint of the sidewalk, next to the buildings and in the middle of the street for building heights of 12.5, 30, 59 and 150 and 200 feet, were modeled to account for the dose contribution from multiple surfaces. Further, photon energies of each radioisotope were incorporated into the modeling. The report “Dose Rate in Contaminated Street” [6] contains a detailed explanation of the process. Side Walk Dose Rate shows that building height doesn't affect the dose rate significantly after 150 feet, as shown in Figure 3. The report also shows a table of the FSURF values used in this calculator for each radioisotope. FSURF values were calculated for each position-specific and building-height specific combination.

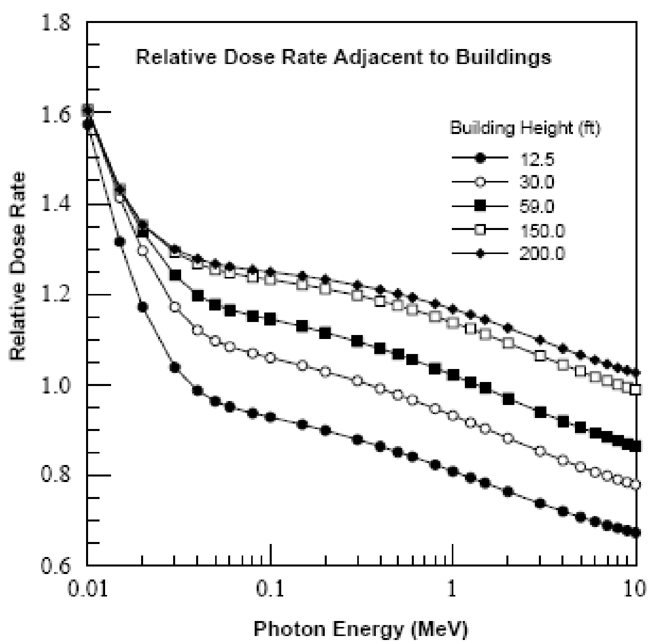

Fig. 3. Relative photon dose rate adjacent to buildings of various heights as a function of photon energy.

Third, for the 2-D exposure models addressing building slabs, a new ACF was developed which is made variable by isotope and area for site-specific analysis. The SPRG calculator allows the user to select from 8 different slab area sizes. If no size is selected for the finite slab analysis, the ACF from the most protective slab size is selected. For further information on the derivation of the isotope-specific/area-specific ACF values for 2-D slabs see the report “Ratios of Dose Rates for Contaminated Slab” [7]. This report indicates that the slab size makes a small difference in comparison to photon energy, which is shown in Figure 4. This report also includes a table of each of these new isotope-specific ACFs for each radionuclide and eight slab sizes.

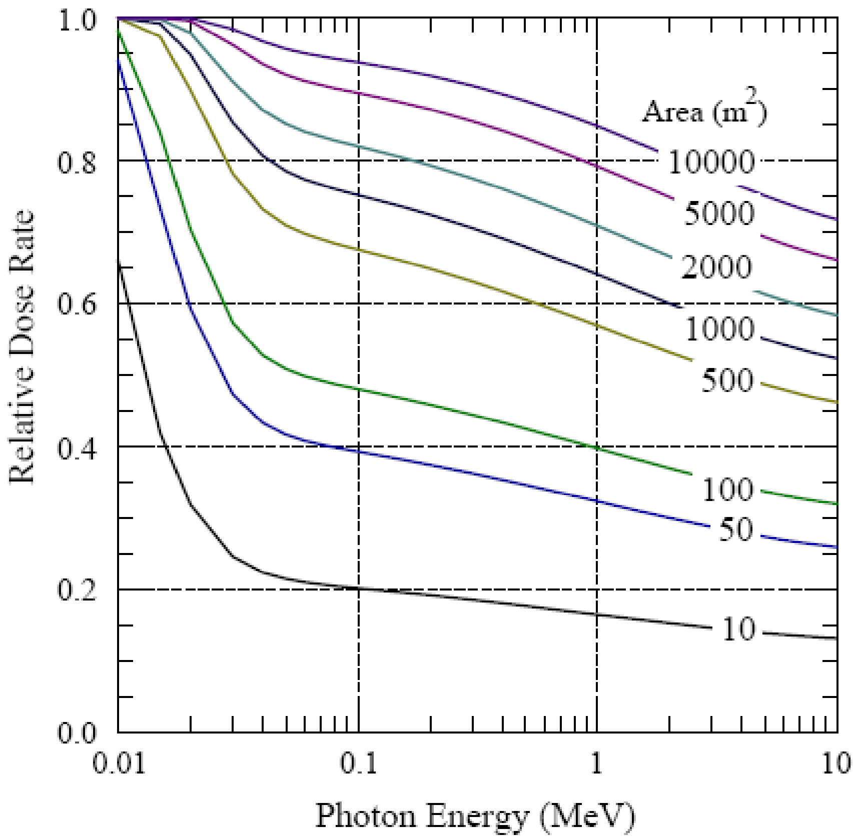

Fig.4. Relative photon dose rate at the center of slabs of various sizes.

MCNP Derived Area Correction Factors (ACFs) for Soil and Concrete

In September 2014, EPA issued a revised PRG calculator with a new set of ACFs for soil in the report "Area Correction Factors for Contaminated Soil for Use in Risk and Dose Assessment Models" [8]. Using MCNP, ACF values for all combinations of 19 source areas (ranging from 1 m^2 to 1,000,000 m2) and 5 source thicknesses of 0, 1, 5, 15, and 200 cm are estimated. In this report are presented ACF values for the 1250 radioisotopes published in ICRP 107. Additionally, presented are ACF values for several decay chains where radioisotopes are identified as "+D" and "+E" which represent 100 and 1000 years of progeny ingrowth respectively.

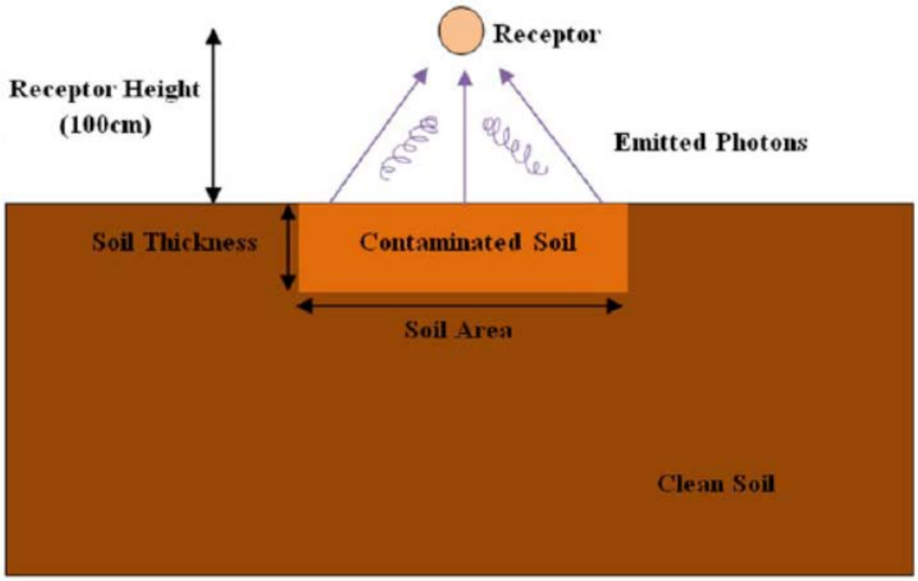

Fig. 5. Geometry used in the soil area correction factor calculation.

In October 2015, an appendix was developed for the ACF report to include ACFs for concrete. The additional tables are area correction factors for areas of concrete to an infinite soil area. The concrete ACFs are used to determine risk from external exposure of a nuclide emanating from a concrete surface or volume. This is done by taking previously established dose coefficients and risk factors and multiplying them by the new concrete ACFs. This new appendix will be issued in the near future as a revision to the 2-D concrete slab exposure scenario in the SPRG calculator.

The derivation of the concrete ACF was done in much the same manner as the original ACFs for soil as shown below:

$$ACF_{C,t,A} = \frac{D_{C,t,A}}{D_{S,t,\infty}}$$

Here $ACF_{C,t,A}$ is the concrete area correction factor for a specified source thickness, t, and source area, A. $D_{C,t,A}$ is the dose rate above a source in concrete of thickness t and area A while DS,t,∞ is the dose rate above a soil source of thickness t and an infinite planar area. ACFs for concrete should be used solely for the risk and dose estimation from a radionuclide in concrete only. Plus D and E concrete ACFs were also calculated which factor for 100 and 1000 years of progeny in-growth respectively. The density of concrete used for the correction factors was 2.3 g/cm3 while the soil density was 1.6 g/cm3.

MCNP Derived Gamma Shielding Factors from Clean Soil

In September 2014, when issuing the revised PRG calculator EPA also included new gamma shielding factors (GSF) from the report “Gamma Shielding Factors for Soil Covered Contamination for Use in Risk and Dose Assessment Models” [9]. Previously in the PRG and DCC calculators, dose rates and risk assessments were based upon values published in

FGR 12 and 13 which assume unshielded soil contamination. It is not appropriate, however, to apply these values in cases involving buried contamination. Due to shielding, covering the contaminated area with soil will produce lower dose and risk coefficients that are stated in the Federal Guidance Report (FGR) 12 and 13. Therefore, gamma shielding factors are needed to apply the published EPA risk values to the buried contamination scenarios. Outdoor gamma shieling factors (GSF_0) are derived by modeling various thicknesses of clean soil covering ground soil contamination. The gamma shielding factor is defined as the ratio of the dose corresponding to covered contamination to that of an unshielded surface source in soil. The MCNP was used to derive kerma values one meter above the soil surface for various
scenarios ranging from 0 cm soil cover to 100 cm soil cover in 10 cm increments while using source thicknesses of ground plane, 1, 5, 15 and infinite.

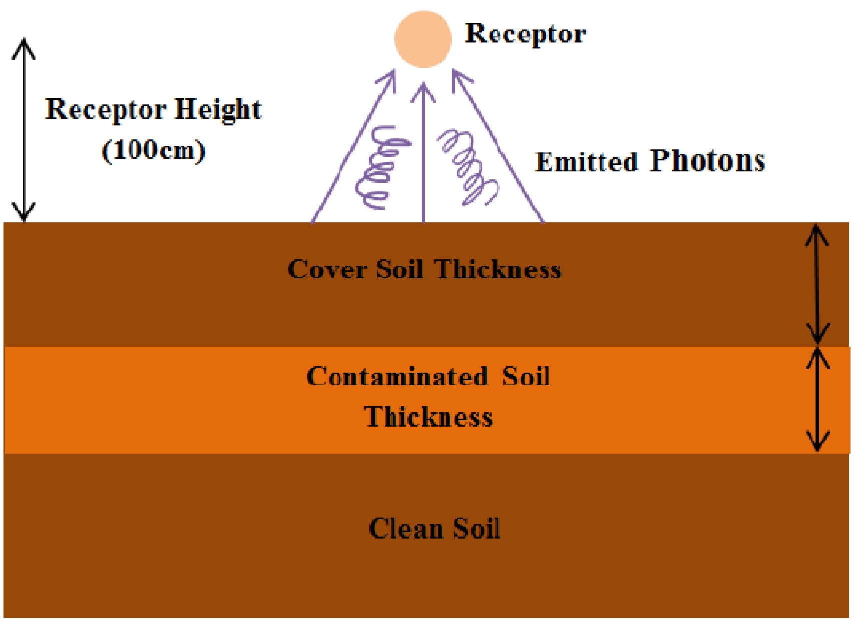

Fig. 6. Geometry of Gamma Shielding Factor Calculation

In September 2015, an appendix to this report was developed which added soil covers of 200 cm to 1000 cm in 200 cm increments. These additional depths were added to ensure that a depth was included for each radionuclide that blocked all external exposure. These additional depths will soon be added to the PRG and DCC calculators.

MCNP Derived Adjustments for Buildings

In September 2015, EPA revised the BPRG and BDCC calculators with a new report "Room Radiation Dose Coefficients for External Exposure" [10] that provided updated F_{SURF} values which were added that account for multiple source depths (ground plane, 1cm, 5cm, 15cm and infinite depth) and multiple building materials (wood, glass, concrete, drywall and adobe mud brick were analyzed as well as 2 composite scenarios). Composite 1 is a drywall room with a glass window, wooden doors and drywall walls. The floors for composite 1 are concrete and the ceiling is drywall. Composite 2 is a concrete room with wooden doors, a drywall ceiling and a concrete floor. Both composite cases used a homogeneous mix of material for the walls to represent the window and door mixed in with the wall. The five room dimensions that were modeled are 10x10x10 ft^3, 50x50x10 ft^3, 100x100x10 ft^3, 200x200x20 ft^3, and 400x400x40 ft^3. Contamination depths of 1, 5, 15, and 100 cm were modeled as well as surface contamination. Contamination was assumed to uniformly cover all six surfaces of the room. Air kerma was found for corner, center, and middle of the wall positions within the room as well as a room average.

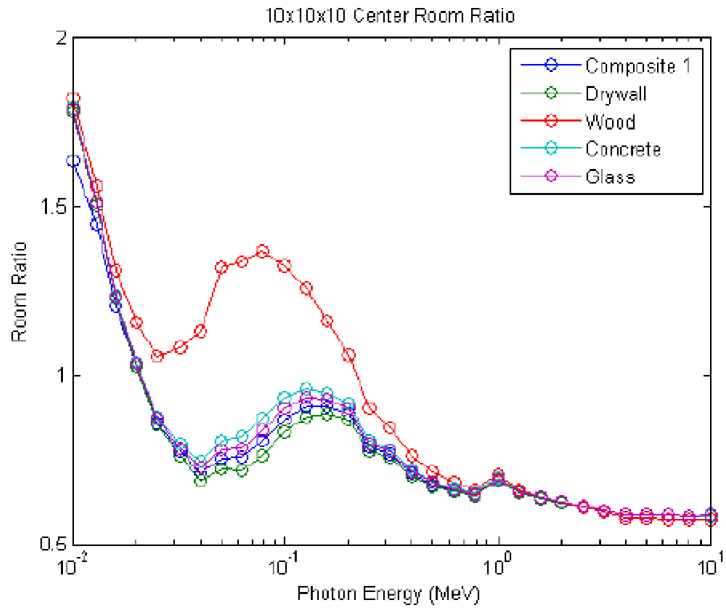

Fig. 7. Composite 1 comparison to individual components center of the room for a 10x10x10 room with surface contamination

MCNP Derived Upcoming Adjustments

An analysis is nearly complete to adjust external exposures for workers in trenches. These adjustment factors will be for the PRG and DCC construction worker scenarios when receptors are assumed to be in trenches for activities such as excavating soil for constructing buildings or laying down or repair utilities. This analysis will include several trench sizes (e.g., depths, lengths, and width). Another analysis has begun of gamma shielding factors for several common building materials and thickness from contaminated soil underlying the structure and in the yard. When completed this analysis will provide potential adjustment factors in the PRG and DCC calculators for different building types.

It is expected these two analyses will be complete by the time of the Waste Management symposium.

RESULTS

In most instances, the more accurate modeling results derived from these gamma adjustments are less conservative. The notable exception are for some radionuclides in rooms with contaminated walls, ceiling, and floors, and the receptor is in location of the room with the highest amount of radiation exposure, usually the corner of small rooms and the center of large conference rooms. The use of MCNP has enhanced the earlier analyses by now including contamination source depth and the density of various materials. The improved scientific basis of these analyses may facilitate stakeholder agreement on site-specific risk and dose assessments that were developed using EPA's calculators.

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