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14b. Justification Details Minor math errors have been corrected in the revision 1 document.				
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204-AR Facility Rail Accident Analysis

J. E. Kelly

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Abstract: This is a probabilistic analysis of the rail car accidents at the 204-AR Waste Unloading Facility.

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204-AR FACILITY RAIL ACCIDENT ANALYSIS

September 19, 1996

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1.0 Purpose

The purpose of this document is to establish and document a train accident likelihood for the Hanford Site, based on commercial train accidents. The Hanford Site has transported radioactive waste by rail without significant incident for many years. The likelihood of a rail accident that could cause undesirable consequences is evaluated in this document. Finding distinct consequences and accident frequencies is left to studies of specific activities.

2.0 Methodology

The following sections describe the process used to derive the frequencies and probabilities used in this analysis. These values, while considered applicable to the Hanford Site, are conservative for reasons described in Section 3.6. Three factors applied in deriving the rail accident frequency are accident statistics, human reliability, and normal operating methods.

3.0 Accident Statistics

3.1 National Statistics. The frequency of a rail transport accident was derived from information provided by the DOT, FRA, and Office of Safety. The accident data for the years 1983 through 1991 were averaged, resulting in the value of 5.4×10^{-9} accidents per mile of train travel. Table 3-1 presents the number of train miles, number of accidents, and accident rate per million train miles for the years 1983 through 1991.

Table 3-1. Train Miles, Accidents, and Accident Rates.

Year	Train miles (millions)	Number of accidents	Accident rate/mile
1983	558,191	3,906	7.00E-9
1984	592,599	3,900	6.58E-9
1985	570,911	3,430	6.01E-9
1986	567,098	2,761	4.87E-9
1987	581,314	2,647	4.55E-9
1988	609,334	3,051	5.01E-9
1989	620,599	3,080	4.96E-9
1990	608,837	3,045	5.00E-9
1991	576,835	2,814	4.88E-9
Totals	5,285,718	28,634	5.42E-9

*Accident rate is given in accidents per million train miles.

3.2 Hanford Site Statistics Hanford Site rail operations appear to have developed a long running safety record regarding injuries and accidents. As an example, although train wheels have slipped off the tracks several times, no train has tipped over or been in danger of tipping over.

3.3 Effectiveness of Train Crew in Preventing Accidents The effectiveness of the train crew in preventing damage if a derailment occurs was evaluated in a separate analysis. This analysis considered the likelihoods of an observer seeing erratic train behavior, the engineer reacting correctly when alerted of the problem, and the brakes applied upon demand. Probabilities for human reliability are based on human reliability analyses (Dougherty and Fragola 1987; Guttman and Swain 1983). It is believed that the probabilities concluded in these analyses are conservative. The event tree for this analysis appears in Figure 1.

Table 3-2. Derailments and Accidents Caused by Track Defects.

Year	Total accidents	Derailments		Track defects	
		Total	% of total accidents	Number of accidents caused by	% of accidents caused by
1983	3,906	3,004	76.9	1,581	40.5
1984	3,900	2,915	74.7	1,481	38.0
1985	3,430	2,495	72.7	1,280	37.3
1986	2,761	2,006	72.7	1,016	36.8
1987	2,647	1,859	70.2	938	35.4
1988	3,051	2,054	67.3	952	31.2
1989	3,080	2,129	69.1	1,019	33.1
1990	3,045	2,146	70.5	988	32.4
1991	2,814	1,936	68.8	968	34.4
Total	28,634	20,544	71.7	10,223	35.7

The analysis considers two human error factors. Failure of a crew member to detect a possible derailment situation has a probability of 6.0×10^{-03} . Failure of the engineer to stop the train has a probability of 1.0×10^{-03} .

Familiarity of the crew with the train and track, inspections, training, and reduced speed of the train reduce the likelihood that a crew member will fail to handle the potential derailment situation (failure to react). Once the erratic movement is observed, the engineer is likely to stop the train. Based on the human reliability analyses (Dougherty and Fragola 1987; Guttman and Swain 1983), these probabilities are considered conservative.

The likelihood that the brakes of the train will not work correctly is 7.1×10^{-4} . This value is the probability of failure of solenoid valves to operate upon demand (Eide et al. 1990). The brakes are assumed to actuate if the air is dumped from the brake system because the brakes are tested when the train is coupled. Mechanical brake failure is less likely than human error.

3.4 Assumptions The analysis starts by considering the kinds of accidents that could cause problems. Typical rail accidents are derailments, collisions between two trains, collisions between a train and a road vehicle, and fires.

Current Hanford site rail operations procedures do not allow trains to operate in a conflicting manner on the Hanford Site tracks; therefore, a collision between two trains is impossible. Collisions between a train and a road vehicle are highly unlikely because waste is normally shipped only during off-peak vehicle usage hours when there is little traffic, and rail crossings along the train route are barricaded. Procedures require carrying only enough fuel to make the round trip reduces the possibility of a fire that could damage the cargo. Additionally, spacer cars separate the engine from the load.

Even if the above accidents could happen, they would have to be severe enough to damage the cargo. For example, two structural analyses of the fuel spacer burial box show that it will not be damaged if it stays on its flat car and the flat car remains upright. Only a severe derailment could cause the fuel spacer burial box to separate from the flat car.

Adherence to strict administrative procedures prevents all accidents other than derailments. Therefore, derailments are the only accidents analyzed. This study was limited to finding the frequency of derailments in which cargo could be damaged. Accident/Incident Bulletins published by the Federal Railroad Administration (FRA) show the frequency of rail accidents to be 5.4×10^{-9} accidents per mile (See Table 3.-2). Derailment causes 71.7% of these accidents.

Several types of mishaps can cause derailments. These include track and equipment failures, human error, as well as a variety of other reasons. Derailment caused by equipment or track failure is unlikely. Because the Hanford site system is small, the railroad personnel are very familiar with it and will likely detect faults. It is expected that the train crew will identify problems and take action to mitigate accidents.

This analysis makes three assumptions. First, not more than two seconds elapses between detection of erratic train behavior and brake actuation. Second, a train travelling 40 km/h (25 mi/h) requires approximately 12 m (40 ft) to stop after the brakes are actuated. Administrative procedures restrict train speed to no more than 40 km/h (25 mi/h) when carrying radioactive material. Third, under the above conditions, the derailed car will remain upright, and that neither it, nor the cargo, will be damaged. The assumptions require no more than a 0.3 g deceleration force. For comparison, large trucks undergo a 0.75 g deceleration force with full brake application (Clarke et al. 1976). Past events on the Hanford Site support

these three assumptions. It should be noted that a derailed train has significant drag and slows rapidly even without brakes.

3.5 Derailment Probability Because operational controls essentially preclude collisions on the Hanford Site rail system, derailment is the only accident with sufficiently high probability to require analysis. It has been assumed that packaging will not be subject to damage if the train remains upright in a derailment.

Table 3-2 provides national derailment and track defect information for 1983 through 1991. During these years, 71.7% of all rail accidents were derailments. Of all accidents, 35.7% were caused by defective tracks. As it is unlikely that defective tracks caused collisions, it was assumed that all the accidents caused by defective tracks were derailments. This assumption leads to the conclusion that defective tracks caused 49.8% of derailments.

Because tracks on the Hanford Site are subject to frequent inspection and restricted train activity, it is unlikely that a derailment caused by track defects will occur onsite. Therefore, 49.8% of the derailments assumed to be caused by defective track are excluded from the event tree. The remaining 50.2% are included in the model.

Derailements at the Hanford Site are rare. There have been several incidents in which train wheels have left the tracks; however, no train has tipped, or been in danger of tipping onto its side. The Hanford Site classifies minor events as derailments that would not be so classified in commercial transportation.

3.6 Normal Operating Methods The speed limits are 40 km/h (25 mi/h) (lower than commercial railroad limits for Class 3 tracks) for normal travel, 16 km/h (10 mi/h) for speed-grade crossings, and 8 km/h (5 mi/h) for spurs at the process facilities. These low-speed limits help maintain lower accident frequencies than commercial rail.

To assure track integrity, the track is inspected no more than eight hours before a radioactive waste shipment where fire must be precluded.

At least three crew members are in the engine cab during shipments with at least one of them assigned to watch the cars constantly for abnormalities. Short train length allows close observation of the loaded car. This procedure is not followed in commercial service. The personnel are experienced, fully trained, and undergo periodic retraining.

Rail shipments are not made during conditions of low visibility such as dense fog or darkness.

Job planning and shipping controls are much more stringent than commercial industry. Before a shipment, all involved parties meet to discuss potential problems as well as normal and emergency procedures.

3.7 Conservatism Considerations No attempt has been made to quantify the level of conservatism in this analysis; however, a qualitative level of conservatism can be established. In addition to the normal operational controls, the following items illustrate that using national rail statistics for accident frequencies and derailment fraction is conservative.

Typically, track and equipment onsite is maintained to higher standards than commercial equipment. The assembly of the track is a higher standard than normally used on commercial track of equal class. Every tie has a tie plate; consequently, more spikes connect the track to the tie. The result is a more stable track with a lower likelihood of track-caused derailments.

The track onsite does not experience the high frequency of use and large loads that are common for commercial tracks.

The track is considered Class 3 while much of the rail where accidents occur in commercial service is of lesser quality (Classes 1 and 2). National statistics show that approximately 48% of all accidents occur on Classes 1 and 2 rail while only about 16% occur on Class 3 rail.

National statistics include accidents occurring at speeds higher than those allowed onsite. High-speed accidents generally result in car-to-car as well as car-to-roadbed interactions. Car-to-car interactions significantly raise the likelihood of tank puncture.

Included in the national statistics are cargos containing gases or highly volatile materials. The percentage of loss for these materials from a given leak is much larger than for aqueous cargos.

Compared to commercial railroads, train lengths (onsite) are short that allow the train to stop in a shorter distance from a given speed. Average commercial trains are composed of 60 cars (Clarke et al. 1976) while onsite trains moving waste consist of three to seven cars. Although the cars may be empty or fully loaded, the rolling mass and inertia of commercial trains are much higher than the rolling mass and inertia of trains onsite. In addition, unloaded flat cars, used as spacers for ALARA concerns onsite, have an even lower mass to interact with other cars.

The above factors will reduce the severity of an accident to less than the national average. However, the national statistics are the basis for this evaluation.

3.8 Operational Controls This section describes operational controls that have been applied for the rail transport of radioactive material at the Hanford Site. These controls are more stringent than those found for commercial rail application, and therefore help reduce the number of accidents or their severity. Table 3-4 shows speed limits and conditions in which they apply.

Table 3-3. Speed Limits and Conditions.

Speed limit (mi/h)	Condition
25	Outside limited area (regardless of load)
10	Inside limited area Crossing paved roads (paved road crossings) When visibility is hampered by fog, smoke, or haze During icy or snowy conditions Within 1 mile of the WPPSS* Site While traversing the WPPSS Site
5	While on a rail spur of any facility (exiting or entering)
4	While coupling

*WPPSS = Washington Public Power Supply System.

The possibility of collisions is minimized by the following factors:

- Train/vehicle - Using gates and signal lights on heavy traffic crossings minimizes the possibility of a collision with a vehicle by limiting the distance that a vehicle may approach the train. The road is blocked on each side of rail crossings to stop vehicle traffic and prevent it from approaching closer than 30 m (100 ft) to the crossing. Crossings that are blocked include paved highway crossings, WPPSS crossings, and all unpaved road crossings within a mile of the WPPSS Site. Collision probabilities are also minimized by slowing the train to 16 km/h (10 mi/h) and warning traffic by blowing the train horn.
- Train/train - Standard train orders govern all train movements. Normal operating procedures and controls are conservative and minimize the probability of an accident involving two trains. A central dispatcher maintains safe separation between trains and other railroad equipment during their movements. Conductors and dispatchers are in constant radio contact.

The possibility of derailments is minimized by the following factors:

- Track - To help preclude a possible derailment or tip-over of a train, the railroad onsite is maintained to the standards of the FRA, 49 CFR 213 by the track maintenance crew and two full-time track inspectors. The entire working portion of the railroad is inspected monthly. Periodically an FRA Track inspector performs an independent inspection. The survey car checks all of the spur and mainline trackage annually except contaminated areas

and out-of-service tracks. Replacement of defective rails found during the inspection has a high priority.

- Train - Before departure, train cars are inspected for potentially hazardous conditions. These conditions include leaning, listing, or sagging of the car body; objects dragging below or extending from the side; broken or missing safety appliances; and other conditions likely to cause an accident. Cars showing any of these defects are not used until they are repaired. Preventive maintenance inspections must be current for the brakes and running gear before a car is loaded.

The possibility of fires is minimized by the following factors:

- Fires can cause, or worsen the effects of, an undesired release. Temperatures high enough to damage many loads can be caused by a vegetation fire alongside the railroad tracks, a collision with a gasoline truck and the resulting fire, or a diesel-fuel fire from the locomotive. Normal operating procedures mitigate the possibility of these fires.
- Track crews spray weed killer every two years in a 3 m (10 ft) swath on either side of the centerline of the tracks, decreasing the possibility of a vegetation fire next to the tracks. Loose tumbleweeds are removed as required.
- A collision with a gasoline truck that results in a fire is minimized by blockading tracks that cross paved roads outside limited areas, signaling traffic with warning lights, blowing the train horn, slowing the train down as it approaches the crossing, and the fact that gasoline truck traffic not on government business is very unlikely. Even if such an accident did occur in the most populated area (300 Area), Hanford Fire Protection Services are readily available.
- The diesel fuel from the locomotive may ignite and burn. To minimize possible damage, spacer cars are placed between the engine and the car carrying the cargo. Trains consist of a locomotive, a cargo car, and at least one spacer car on each side of the cargo car. Up to four spacer cars may be used between the locomotive and the cargo car and up to two spacer cars may be used behind the cargo car. The train does not exceed seven cars. Diesel fuel in the locomotive is limited to the amount required for the trip plus a reasonable safety factor, as determined by operating personnel.
- Hanford Fire Department personnel are notified before shipment.

4.0 Results

This study shows that the Hanford site has placed many administrative controls on the use of trains even though the frequency of a rail accident is relatively small based on data on commercial trains. The frequency of rail

accidents per mile is 5.4×10^{-9} accidents per mile, based on commercial data. It has also been shown that 71.7% of these accidents (3.9×10^{-9}) are caused by derailments.

The accidents of concern are those in which radioactive material could be released to the environment. The rail transportation event tree is shown in Figure 2. The top events are described below.

Shipping activity - initiate rail shipping activity. The event tree starts with the initiator, the shipping activity, which is given a normalized occurrence factor of 1.00.

Accident - rail accident (accidents per mile). This event divides the rail activity according to accident occurrence. The lower branch, "accident occurs," has a frequency of 5.4×10^{-9} accidents per mile. Because this value is so small, the computer code shows a unity probability of "no accident" on the upper branch. Section 3.1 provides a description of the derivation of this frequency.

Derailement - not caused by equipment failure. Because derailments are the only accidents that can cause undesired consequences, this branch divides the accidents according to derailment occurrence. The probability of a derailment, given that an accident has occurred, is 7.2×10^{-1} . Section 3.3 describes the derivation of this probability.

Defective track - defective track as reason for derailment. The level and stringency of track inspection and the low stress placed on the rails by train activity at the Hanford Site preclude derailments caused by track defects. For conservatism, FRA data for track defects and derailments were used to calculate that 49.8% of all derailments are caused by track defects. Therefore, this branch divides the derailments according to whether they were caused by defective track or other reasons. The total number of derailments was reduced by the number of derailments caused by track defects, roadbed, and structure failures. It was assumed that accidents caused by defective track will result in derailments. The probability that defective track causes a derailment is 4.98×10^{-1} . Section 3.5 provides a description of the derivation of this probability.

Crew action - effect of train crew action on damage. A train can derail with little or no warning. However, given this situation, the train crew can still stop the train before damage is serious. This event considers the probability that the train crew will mitigate an accident by taking proper actions. The crew is expected to notice all problems and take the appropriate actions. The probability that the crew does not mitigate the accident is 7.7×10^{-3} . This value is the summation of the sequence probabilities in Figure 1 that resulted in damage:

$$(7.05 \times 10^{-4} + 9.94 \times 10^{-4} + 6.00 \times 10^{-3}).$$

Location - derailment location causes rollover. This event divides the situations in which the crew does not prevent damage according to whether the train rolls over or not. A train may derail on flat terrain or where there are no embankments along the track. It is expected to remain upright if it derails in such a location. The probability that the train could roll if it were to derail is 2.8×10^{-1} . This reflects the percentage of track along embankments.

The event trees shows how the accident frequency was developed. It will be necessary for the analyst to add packaging vulnerability to the event tree to find a realistic value of the frequency of unacceptable or undesirable consequences. For example, the rail-transport event tree determined an accident frequency of 5.3×10^{-9} derailments with rollovers per mile. If the cargo can sometimes withstand the rollover, the accident frequency should be multiplied by the probability that the cargo will survive the rollover. Conversely, if the cargo can be damaged even if a rollover does not occur, the accident frequency for derailment without a rollover must be multiplied by the probability that the cargo will be damaged without a rollover.

5.0 Conclusions

Based on the commercial data, it is apparent that train accidents per mile are extremely unlikely. If probabilities could be placed on administrative controls used at Hanford, train accidents would be incredible. Normally, human error probabilities are placed on such failures, making the operation of trains and accidents incredible. Specifically, the 204-AR Waste Unloading Facility will use trains to transport waste. There is an interest in the probability or frequency of a train derailment and railcar breach at that facility. An event tree will be used to describe the relationship of events considered in this accident. These events and probabilities assigned are described below.

1. The event tree was set up to assume twelve train shipping activities per year at the 204-AR building.
2. The number of rollover train accidents at Hanford is based on data given in the report above.

3. The tracks are inspected regularly for damage at Hanford as described above. The probability for this event is included in the rollover frequency.
4. Speed rules for trains at Hanford are described above. Therefore, the basic frequency includes this.
5. If the doors on building 204-AR were left closed and the train ran into them, it is unlikely that the waste would spill; but again a probability of 0.5 was conservatively applied to the doors being closed.
6. There is a question as to whether or not waste would be present on the train. It should be present in only one direction, so a probability of 0.5 was applied.
7. Once there is a train accident, there is a question as to whether or not the waste is involved in a fire. A probability of $1.0\text{E-}02$ was applied to this event (Fischer).

The event tree developed is shown on Figure 3. The accident involving a release of radioactive waste was found to have a frequency of 3.27×10^{-9} per year based on twelve activities per year. For it to catch on fire would be 3.30×10^{-11} per twelve activities per year.

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Figure 3-1 Crew Action Fails to Prevent Damage

RAIL CAR EXHIBITS SYMPTOMS OF DERAIL EVENT	OBSERVER SEES RAIL CAR BEHAVING ERRATICALLY	ENGINEER REACTS TO NOTIFICATION AND PLUGS IT TO STOP TRAIN	BRAKES SET AND STOP TRAIN BEFORE DAMAGE OCCURS TO RAIL CAR	SEQ. PROB.	CLASS
CAR ERRATIC	OBSERVER	ENGINEER	BRAKES		
				9.92E-01	SUCCESS
		RESPONDS	BRAKES WORK		
			7.10E-04 BRAKES FAIL	7.05E-04	DAMAGE
	OBSERVES				
		1.00E-03 NO REACTION		9.94E-04	DAMAGE
1.0 CAR ERRATIC	5.00E-03 NO OBSERVATION			5.00E-03	DAMAGE

CREW ACTION FAILS TO PREVENT DAMAGE DERAIL TRE 9-19-96

Figure 3-2 Generic Rail Transportation Risk Assessment

Figure 3-3 Railcar Accident Entering 204-AR Building

ACTIVITY INVOLVES TRAIN NEAR 204-AR	DERAILMENT PER MILE AND ROLLOVER	204-AR BUILDING DOORS OPEN	NO WASTE ON TRAIN	FIRE OCCURS THAT AFFECTS WASTE	SEQ. PROB.	CLASS
ACTIVITY	ACCIDENT	DOORS CLOSED	WASTE	FIRE		
12. ACTIVITY	1.10E-09 ROLLOVER	.50 DOORS CLOSED	.50 WASTE	1.00E-02 FIRE	1.20E+01	OK
					3.30E-09	OK
					3.27E-09	OK
					3.30E-11	OK
					3.30E-09	OK
					3.27E-09	RELEASE
					3.30E-11	FIRE

RAILCAR ACCIDENT ENTERING 204-AR BUILDING 204-AR.TRE 9-19-96

CHECKLIST FOR PEER REVIEW

Document Reviewed: 204-AR Facility Rail Accident Analysis Rev 1

Scope of Review: Review of corrected math errors in original report

Yes No NA

☐	☐	☒	*	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
☒	☐	☐		Problem completely defined.
☒	☐	☐		Accident scenarios developed in a clear and logical manner.
☒	☐	☐		Necessary assumptions explicitly stated and supported.
☐	☒	☐		Computer codes and data files documented.
☒	☐	☐		Data used in calculations explicitly stated in document.
☒	☐	☐		Data checked for consistency with original source information as applicable.
☒	☐	☐		Mathematical derivations checked including dimensional consistency of results.
☒	☐	☐		Models appropriate and used within range of validity or use outside range of established validity justified.
☒	☐	☐		Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
☐	☐	☒		Software input correct and consistent with document reviewed.
☐	☐	☒		Software output consistent with input and with results reported in document reviewed.
☐	☐	☒		Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
☒	☐	☐		Safety margins consistent with good engineering practices.
☒	☐	☐		Conclusions consistent with analytical results and applicable limits.
☒	☐	☐		Results and conclusions address all points required in the problem statement.
☒	☐	☐		Format consistent with appropriate NRC Regulatory Guide or other standards
☐	☐	☒	*	Review calculations, comments, and/or notes are attached.
☒	☐	☐		Document approved.

Milton V. Shultz

Reviewer (Printed Name and Signature)

9/19/96

Date

* Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. Such material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

9/19/96

CHECK CALCULATIONS

for WDC-SD-HM-CN-021
Mr. V. Shultz 9/19/96

REV. 1

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year	Train mi	No Acc	acc/mi
1983	558,191X10 ⁶	3,706	6.9976 X10 ⁻⁹
1984	592,579X10 ⁶	3,906	6.5872 X10 ⁻⁹
1985	570,911X10 ⁶	3,936	6.0079 X10 ⁻⁹
1986	567,058X10 ⁶	2,721	4.8686 X10 ⁻⁹
1987	501,314X10 ⁶	2,647	4.5535 X10 ⁻⁹
1988	609,334X10 ⁶	3,051	5.0071 X10 ⁻⁹
1989	620,571X10 ⁶	3,086	4.9629 X10 ⁻⁹
1990	608,837X10 ⁶	3,045	5.0013 X10 ⁻⁹
1991	576,835X10 ⁶	2,814	4.8783 X10 ⁻⁹
Totals	5,2857X10 ¹²	28634	→ total = 6.6558 5.4172X10 ⁻⁹

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

→ Charles with 5.41724 X10⁻⁹ acc/mi
Total is irrelevant. Since acc rates in based on total mi and total accidents.

Accidents Caused by Track Defects.

Year	acc	Derail	%	Track defects	%
1983	3906	3004		1561	
1984	3900	2915		1461	
1985	3486	2445		1250	
1986	2761	2006		1016	
1987	2647	1859		938	
1988	3651	2054		952	
1989	3086	2129		1019	
1990	3045	2146		988	
1991	2814	1936		968	
Totals	28634	20544	71.7469	10223	35.7023

→ check with CN value 71.7

→ check with CN value 35.7

20544 derail

→ track defects/derail = 49.7614

50.2345 % of derails would not track related

= 10321 total acc 1983-1991 not track related derails.

→ check with CN 49.8

5.42X10⁻⁹ X 72 X .5 X 7.70X10⁸ X .28 = 4.266787X10⁻¹² → check with CN value 4.20X10⁻¹²
 12 X 5.42X10⁻⁹ X .5 X 7.70X10⁸ X .28 = 1.122 X10⁻¹¹ → check with CN value 1.122 X10⁻¹¹
 12 X 5.42X10⁻⁹ X .5 X 7.70X10⁸ X .28 = 1.122 X10⁻¹¹ → check with CN value 1.122 X10⁻¹¹

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