APPLICATIONS OF RADTRAN 4 TO ROUTE-SPECIFIC ANALYSIS*

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ABSTRACT

The transportation risk evaluation code RADTRAN 4 is designed to evaluate doses and risks associated with the transportation of radioactive materials (1). RADTRAN 4 may be used to calculate dose consequences for incident- free transportation and dose risks for accidents. Consequences of normal (or incident-free) transportation include doses to crew members, persons at stops, and members of the public sharing a route segment (on-link) and residing near the segment (off-link) during normal transportation. These dose estimates are not multiplied by a probability factor and, hence, are referred to as dose consequences. Calculated doses that might be incurred during accidents are multiplied by the probabilities of those accidents, and hence are referred to as dose risks. RADTRAN 4 includes a LINK option that allows the user to characterize each link or segment of a transportation route in greater detail than that provided by average or default values for route-related parameters. The LINK option increases the flexibility of the code in several ways:

- LINK allows the same route segment to be evaluated under a variety of conditions. This capability may be used to prepare environmental documentation and to evaluate alternative routes under U.S. Department of Transportation Docket HM-164 (49 CFR 171-177);
- LINK capability may be used to assess the impact of projected population shifts on transportation routes;
- LINK facilitates comparison of the national average data included as defaults in RADTRAN with available "route-specific" data.

SAMPLE PROBLEM

In order to illustrate its flexibility, the LINK option was used to address a hypothetical assessment of the impact of projected population growth. The LINK option was used to evaluate two routes: Route 1 originates at the Port of Seattle and terminates at the Idaho National Engineering Laboratory (INEL) in Idaho, while Route 2 originates in San Diego, California, and terminates at the Hanford Reservation in Washington. Route 1 includes portions of Interstate Routes 5, 90, 82 and 84 through Washington and Idaho; Route 2, almost the entire length of Interstate 5 through California, Oregon, and Washington, and Interstate 90 and 82 in Washington. These are among the many hundreds of Interstate routes that have been or could be used for actual radioactive materials shipments. They were selected because one of the authors (R.F.W.) resides in the area and has driven both routes a number of times.

A random sampling process was used to divide Route 1 into 30 segments and Route 2 into 36 segments. To ensure that the entire route was sampled, the route was first divided into 10 equal segments. Then 3 points in each segment were selected with a random-number generator, and the population density at each point determined from information published by the U.S. Bureau of the Census (2). The points were examined to make sure that all population centers along the routes had been sampled, and additional points were generated, if required. In this manner, each route was divided into a minimum of 30 segments. Starting from the origin, the entire length of the first segment was assigned a population density equal to that of the first point; the second segment was assigned the population density of the second point, and so forth. The resulting "route-specific" segment data comprise the baseline routes (Table I). Consequence and risk values were calculated for these baseline routes and compared with values for the same routes with different projected future population densities. The segment data were developed solely for the purpose of this study; an up-to-date routing code with a population overlay capability would be used for actual calculations.

Metropolitan areas along both of these routes are expected to grow in population, but the population densities of isolated towns is not expected to increase. For the present study, a population density representative of an entire metropolitan area was used to describe route segments traversing each such area. Thus, projected population shifts within a metropolitan area (e.g. between suburbs and the urban core) are not considered.

The baseline population densities for these metropolitan areas were increased by factors of 2, 3, and 4 to reflect

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TABLE I

Seattle, WA, to INEL: Baseline Route

Segment No.	Length(km)	Description	Population per km^2	
		Washington State:		
1	67	Seattle	2585	U
2	39	King Co., E. of Northbend	284	S
3	22	Kittitas Co., I-90, Exit 62	5	R
4	38	Kittitas Co., Tennaway	5	R
5	90	Thorp	5	R
6	27	Kittitas Co., I-90, S. of Exit 3	5	R
7	24	Yakima Co., Granger	19	R
8	38	Yakima Co., I-82, Exit 69	19	R
9	36	Prosser	121	S
10	22	Benton Co., I-92, Exit 102	3	R
11	109	Benton Co., Plymouth	3	R
		Oregon:		
12	18	Umatilla Co., I-84, Exit 179	8	R
13	45	Umatilla Co., I-84, Exit 234	8	R
14	118	Union Co., I-84, Exit 252	5	R
15	30	Union Co., I-84, Exit 261	5	R
16	6	Baker Co., Durkee	2	R
17	137	Malheur Co., I-84, N. of Ontario	1	R
18	18	Ontario	281	S
	4	Idaho:		
19		Elmore Co., I-84, Exit 74	3	R
20	34	Elmore Co., I-84, Exit 90	3	R
21	3	Elmore Co., I-84, Jcn. US51	3	R
22	50	Elmore Co., Glenn's Ferry	3	R
23	84	Elmore Co., E. of Glenn's Ferry	3	R
24	50	Jerome Co., Hazelton	11	R
25	10	Cassia Co., I-84, Jcn. I-86	4	R
26	40	American Falls	97	R
27	1	American Falls	97	R
28	100	Pocatello	870	S
29	5	Pocatello	870	S
30	101	INEL	1410	U

potential growth scenarios (2). These growth scenarios are based on state population projections, historical growth patterns since World War II, and scenarios of change in the basic industries of the region. No increase in population is predicted in any scenario that is greater than a factor of 4 over present levels in the next 30 years (3). Rural areas and isolated towns are modeled in this study as remaining unchanged, to reflect recent land use and growth management legislation (4) and the decline of the timber industry in the Pacific Northwest (5).

Accident dose risk, which uses about an order of magnitude smaller than total incident-free dose, is related to surrounding population density along a route and is considered in this study without modification. Total incident-free dose, on the other hand, is not a useful parameter for this study because the largest components of incident-free dose are relatively insensitive to route-specific parameters such as population density. These insensitive components are: stop dose, crew dose, handler and inspector dose (if any). Thus, this study examines only the minor components of total incident-free dose (off-link and on-link doses) that are directly sensitive to route-specific parameters.

Table II is an example of RADTRAN 4 LINK input data for the baseline for Route 1. Each route segment was assigned a link number. Segments are classified as "urban" in character if the population density was 1000 person/km^2 or greater, as "suburban" if between 100 and 1000 persons/km^2, and as "rural" if less than 100 persons/km^2. Projected changes in population density were reflected as data changes for affected links (i.e. those representing metropolitan areas that are expected to grow), while the population densities assigned to the remaining links remained unchanged.

A potential difference in the "urban," "suburban," and "rural" designations in RADTRAN is the user-definable building shielding factors [i.e. RADTRAN parameters RR, RS, and RU]. These factors are intended to reflect shielding of persons in buildings of varying construction. Default values are available, and the value for RU (0.018 for reinforced concrete) is smaller than that for RS (0.87 for residential

TABLE II

Link Screen of RADRAN 4

LINK	1	4.30E+01	8.20E+01	1.37E+03	2.80E+03	1.60E-05	U	1
LINK	1	1.00E+02	8.20E+01	2.32E+02	7.80E+02	3.00E-06	S	1
LINK	1	9.90E+01	8.20E+01	3.11E+03	2.80E+03	1.60E-05	U	1
LINK	1	6.00E+01	8.20E+01	9.06E+02	7.80E+02	3.00E-06	S	1
LINK	1	1.30E+01	9.20E+01	2.70E+01	4.70E+02	1.32E-07	R	1
LINK	1	1.97E+02	9.20E+01	2.70E+01	4.70E+02	1.32E-07	R	1
LINK	1	5.50E+01	9.20E+01	4.40E+01	4.70E+02	1.32E-07	R	1
LINK	1	8.40E+01	9.20E+01	4.40E+01	4.70E+02	1.32E-07	R	1
LINK	1	9.10E+01	9.20E+01	3.70E+01	4.70E+02	1.32E-07	R	1
LINK	1	4.00E+00	8.20E+01	5.10E+03	2.80E+03	1.60E-05	U	1
LINK	1	9.50E+01	8.20E+01	1.36E+02	7.80E+02	3.00E-06	S	1
LINK	1	8.90E+01	9.20E+01	5.50E+01	4.70E+02	1.32E-07	R	1
LINK	1	4.10E+01	9.20E+01	6.00E+00	4.70E+02	1.32E-07	R	1
LINK	1	4.10E+01	9.20E+01	8.00E+00	4.70E+02	1.32E-07	R	1
LINK	1	1.67E+02	8.20E+01	1.57E+02	7.80E+02	3.00E-06	S	1
LINK	1	6.00E+01	9.20E+01	1.60E+01	4.70E+02	1.32E-07	R	1
LINK	1	1.00E+01	9.20E+01	3.00E+00	4.70E+02	1.32E-07	R	1
LINK	1	1.50E+02	9.20E+01	3.00E+00	4.70E+02	1.32E-07	R	1
LINK	1	6.00E+01	9.20E+01	1.80E+01	4.70E+02	1.32E-07	R	1
LINK	1	2.00E+01	9.20E+01	8.00E+00	4.70E+02	1.32E-07	R	1
LINK	1	2.00E+02	9.20E+01	8.00E+00	4.70E+02	1.32E-07	R	1
LINK	1	6.00E+01	9.20E+01	8.10E+01	4.70E+02	1.32E-07	R	1
LINK	1	8.00E+01	8.20E+01	1.51E+03	2.80E+03	1.60E-05	U	1
LINK	1	2.00E+01	9.20E+01	1.40E+01	4.70E+02	1.32E-07	R	1
LINK	1	3.00E+01	9.20E+01	1.40E+01	4.70E+02	1.32E-07	R	1
LINK	1	2.00E+01	9.20E+01	1.40E+01	4.70E+02	1.32E-07	R	1
LINK	1	3.50E+02	8.20E+01	1.24E+02	7.80E+02	3.00E-06	S	1
LINK	1	3.00E+01	8.20E+01	5.32E+02	7.80E+02	3.00E-06	S	1
LINK	1	1.00E+01	9.20E+01	2.90E+01	4.70E+02	1.32E-07	R	1
LINK	1	3.73E+01	9.20E+01	1.40E+01	3.00E+02	1.32E-07	R	1
LINK	1	7.94E+01	9.20E+01	1.40E+01	3.00E+02	1.32E-07	R	1
LINK	1	1.13E+02	8.20E+01	9.58E+02	1.40E+03	1.60E-05	U	2
LINK	1	6.19E+01	8.20E+01	3.00E+00	4.70E+02	1.32E-07	R	2
LINK	1	6.55E+01	8.20E+01	1.00E+00	4.70E+02	1.32E-07	R	2
LINK	1	1.00E+02	8.20E+01	6.95E+02	1.40E+03	1.60E-05	U	2

frame and/or masonry construction). These values are automatically "called" when the user designates a link as being "urban" or "suburban" in character (under the keyword ZONE in Table II). Since some segments are reclassified from "suburban" to "urban" in some growth scenarios, the change in default value of the shielding factor introduces a potential complication. This effect was examined by comparing off-link risk values obtained with the defaults with adjusted off-link risk values obtained by setting RU equal to RS. All modelled transportation was by tractor-trailer on limited-access freeways at 82 km/hr in urban and suburban areas and at 92 km/hr elsewhere. RADTRAN 4 default data for vehicle density and accident frequency were used. Default values for both of these parameters also vary depending on whether a link is designated as "urban," "suburban," or "rural," but the effect of these parameters on reclassified links was not examined here.

A baseline dose consequence was estimated by calculating with RADTRAN 4 the consequences of transporting, without incident, a single hypothetical truck shipment of pressurized-water-reactor (PWR) spent nuclear fuel with a dose rate of 14 mrem per hour at 1 meter from the package surface [i.e., RADTRAN parameter *TIPKG* = 14]. A spent fuel shipment was modelled solely for purposes of analysis, because shipment parameters are available (e.g. 6), not because any such shipment is actually expected to occur on these routes. After the incident-free off-link and on-link consequences were calculated for the baseline case, the calculation was repeated for new population-density values for the various segments. Similar calculations were performed for accident risk.

RESULTS AND DISCUSSION

Each RADTRAN 4 output lists dose values individually for each link; these are shown in Tables III and IV and Figs. 1a through 2b. Differences between present and projected future segments are easily identified. Although population density is not expected to increase by more than a factor of 4 during the next 30 years (3), the projections were carried out beyond these realistic bounds in order to illustrate features of the LINK option and to highlight the pitfalls of extrapolating beyond one's data base.

Figures 1a and 2a show the calculated dose consequence for incident-free transportation for the off-link and on-link populations of Route 1 and Route 2, respectively. In Fig. 1a, the unadjusted off-link dose consequence for the off-link population appears to be less when the projected population is four times the baseline than when the projected population is only three times the baseline. This occurred because the building shielding factor R was changed from the suburban (RS) to the urban (RU) default value, which is lower. In the United States today, a shift from moderate to high population density is typically accompanied by construction of reinforced

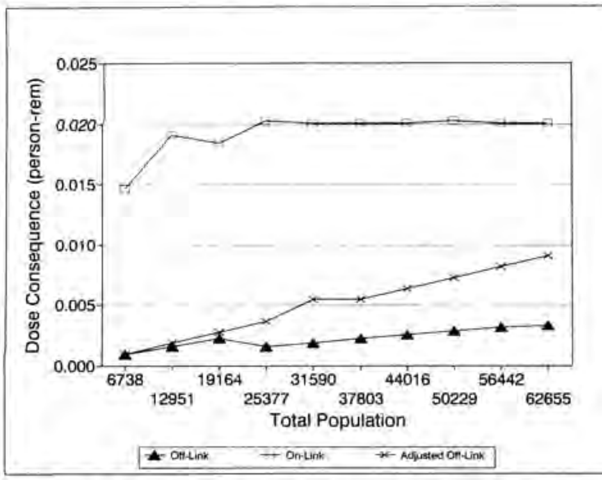

Fig. 1a. Seattle to INEL incident-free transportation.

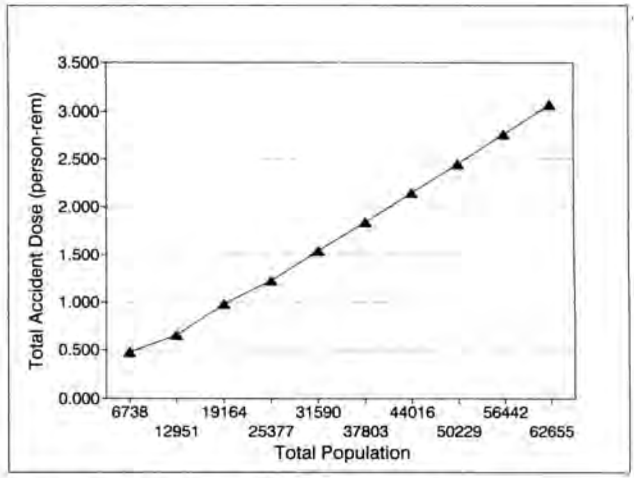

Fig. 1b. Seattle to INEL transportation accidents.

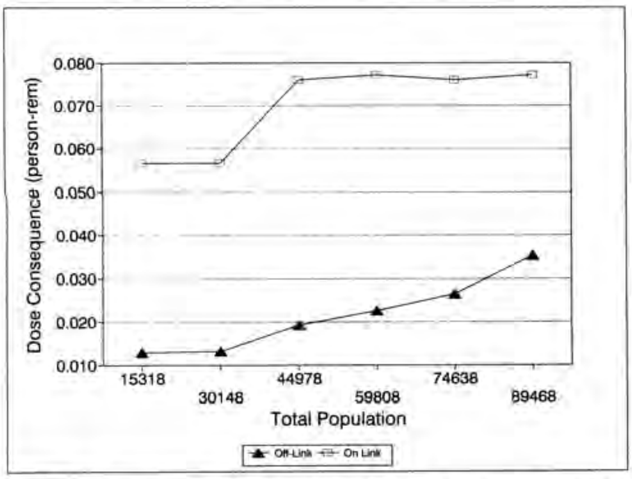

Fig. 2a. San Diego to Hanford. Incident-free transportation.

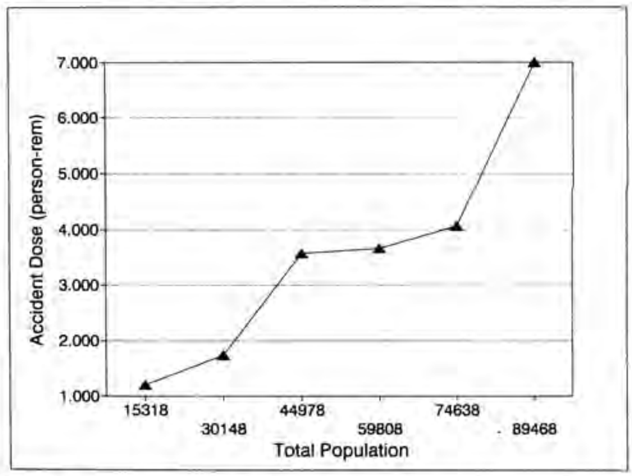

Fig. 2b. San Diego to Hanford. Transportation accidents.

concrete buildings (apartment buildings, office buildings, etc.) with lower shielding factors, which replace preexisting masonry and/or frame buildings. Predicting the degree to which this shift may have proceeded in each growth scenario was beyond the scope of this paper, however, and the shielding factor effect was removed by setting RU equal to RS (and multiplying by 0.1 to facilitate graphical representation). The resulting adjusted values of off-link dose (Tables III and IV; Figs. 1a and 2a) show that off-link dose consequence exhibits a linear dependence on total population density. For both routes, the calculated dose consequence for the on-link population remains essentially constant after the first projected increase, because it is primarily a function of vehicle density, and the vehicle- density parameter was not increased above the default value regardless of the magnitude of the population density increase. That is, once an area was classified as "urban," no further increase in the vehicle density was made; the parameter was in effect held constant thereafter. The on-link dose consequence changed little thereafter as well, demonstrating the direct dependence of this dose estimate on vehicle density. The relationship depicted here is not necessarily incorrect, however, because vehicle density is not expected to increase linearly with population density; urbanization is typically accompanied by expansion of public transportation services and other measures to reduce traffic density. This parameter should be carefully estimated for actual studies.

Results are shown for accident risks in Figures 1b and 2b. Since shipment data are held constant in these examples, and since RADTRAN default accident frequencies were used, the only route-specific components of the risk calculations are population-density projections. The "suburban" to "urban" shift is evident in Fig. 2b but not in Fig. 1b. Route 1 (Fig. 1b) is comparatively short and is dominated by the populations of the metropolitan centers, whereas the longer Route 2 (Fig. 2b) has a higher proportion of rural segments, which masks the shift. These examples also demonstrate that within each zone, accident risk is a linear function of population density. However, in an actual analysis projected accident rates would not be constant, and there might be no apparent linearity.

The advantages and disadvantages and even the definition of route-specific risk analysis have been the subject of much discussion. A major disadvantage is that high-resolution, high-quality data for most parameters, including off-link population density and on-link vehicle density, are not always available; nor are methods of estimating future values of these parameters. However, the route-specific analysis capability of RADTRAN 4 remains a powerful tool for comparing one route with another and for comparing the same route in different conditions. As this study demonstrates, RADTRAN can yield valuable insights regarding the importance of various

TABLE III

Dose and Risk Projections for Route 1 for Baseline and Nine Growth Scenarios* (person-rem)

Total Urban & Suburban Population	Total Population	Incident-Free Dose		Total Accident Dose Risk
		Adjusted Off-link*	On-link	
6213	6738	1.07E-03 (9.24E-04)	1.67E-02	4.71E-01
12426	12951	1.99E-03 (1.57E-03)	2.11E-02	6.51E-01
18629	19164	2.91E-03 (2.24E-03)	2.09E-02	9.75E-01
24852	25377	3.83E-03 (1.55E-03)	2.27E-02	1.22E+00
31065	31590	5.67E-03 (1.89E-03)	2.25E-02	1.54E+00
37278	37803	5.67E-03 (2.11E-03)	2.25E-02	1.84E+00
43491	44016	6.61E-03 (2.54E-03)	2.25E-02	2.14E+00
49704	50220	7.50E-03 (2.87E-03)	2.27E-02	2.45E+00
55917	56442	8.45E-03 (3.20E-03)	2.41E-02	2.76E+00
62130	62655	9.40E-03 (3.33E-03)	2.41E-02	3.08E+00

* Adjusted values from RS = RU and multiplication by 0.1; unadjusted values are in parenthese.

TABLE IV

Dose and Risk Projections for Route 2 (San Diego to Hanford) for the Baseline and Five Growth Projections

Total Urban & Suburban Population	Total Population	Incident-Free Dose		Total Accident Dose Risk
		Adjusted Off-link*	On-link	
14830	15318	1.28E-03	5.65E-02	1.20E+00
29660	30148	1.31E-03	5.65E-02	1.74E+00
44490	44978	1.92E-03	7.59E-02	3.56E+00
59320	59808	2.26E-03	7.72E-02	3.66E+00
74150	74638	2.64E-03	7.59E-02	4.06E+00
88980	89464	3.52E-03	7.72E-02	7.00E+00

* Adjusted values from RS = RU and multiplication by 0.1.

route-specific input parameters. For example, one might attempt to model the functional dependence of the building shielding factor and traffic density parameters on population density.

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