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MEMORANDUM FOR: Malcolm Knapp, Chief
Geotechnical Branch
Division of Waste Management, NMSS

FROM: Frank J. Congel, Chief
Radiological Assessment Branch
Division of Systems Integration, NRR

SUBJECT: REVIEW OF PROPOSED CHANGES TO THE HYDROLOGICAL MODELS IN THE LADTAP II COMPUTER CODE

PNL is currently preparing a comprehensive users guide for the LADTAP II computer code. As part of this effort the hydrological models in the code have been reviewed by PNL personnel and several revisions to the models have been proposed. The purpose of this memo is to request the assistance of R. Codell of your staff in reviewing the attached PNL proposed revisions. This request has been discussed with R. Codell because he is very familiar with the hydrological models in LADTAP II, and has previously assisted us in ensuring the integrity of the models.

If you have any questions about the PNL proposal, please contact M. Wangler at X28900. Your assistance in reviewing the proposal as soon as possible will be greatly appreciated.

Original signed by
F. J. Congel

Frank J. Congel, Chief
Radiological Assessment Branch
Division of Systems Integration

Enclosure:
As stated

cc: R. Bernero
D. Muller
R. Codell
R. Ballard

CK-25

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TASK PLAN REVISION #2

REVIEW OF THE HYDROLOGIC SURFACE WATER COMPONENTS
COMPRISING NRC'S LADTAP II COMPUTER CODE

March 26, 1985

REVIEW OF THE HYDROLOGIC SURFACE WATER COMPONENTS
COMPRISING NRC'S LADTAP II COMPUTER CODE

I. INTRODUCTION

The LADTAP II code was developed to specifically address radiation dose to man. Doses for the general population are calculated as a function of age group and pathway for appropriate body organs.

Radionuclides can be released to the environment through a number of pathways before exposure to man. Several of these pathways include groundwater, nontidal river, open coast, estuary, impoundment, groundwater, overland, and atmospheric. The original LADTAP II documentation (Simpson and McGill 1980) includes incomplete descriptions of four of these pathways: nontidal river, open coast (lake), estuary, and impoundment. The documentation on these four pathways is presented in Regulatory Guide 1.113; the documentation though only includes a sketchy description of the pertinent equations for each of the four pathways.

II. OBJECTIVE

The overall objective of the project (User's Guide to LADTAP II code) is to prepare a document that adequately describes the use of the LADTAP II computer code in performing radiological impact analyses of radioactive liquid effluents from normal operations of light water reactors. This task specifically addresses those portions of the LADTAP II code focusing on the hydrologic components. The primary work of this task has been outlined previously in a task plan submitted to the Project Manager on April 19, 1984. This original Task Plan was developed to review and document the hydrologic component of the LADTAP II code. The original Task Plan does not address aspects dealing with the development of numerical components for the LADTAP II code.

Currently, the numerical algorithms comprising the LADTAP II code do not consider any of the pathways mentioned above except for the impoundment pathway (and only a partial listing). Because only impoundments are considered as a transporting medium by the LADTAP II code, the code has limited use. In an effort to expand the functional use of LADTAP II to other environs, other transporting pathways are being proposed to be included in the code. The proposed additional pathways include nontidal river, lake, impoundment, and groundwater (i.e., saturated zone). Each pathway would be described by its own numerical algorithms and, in effect, represent an individual model that addresses each pathway. For purposes of consistency, the additional algorithms describing each pathway in each model will be based on the equations outlined in Regulatory Guide 1.113.

III. SCOPE OF WORK

The proposed work outlined in this revision to the original Task Plan specifically addresses the developmental work and resource requirements that are necessary to expand the LADTAP II code to address other radionuclide transporting media.

The revisions to the original Task Plan encompass the following work:

- investigating the appropriateness of various pathways and codes addressing said pathways
- developing algorithms or programs addressing the following pathways
    - nontidal rivers
    - lakes
    - impoundments
    - groundwater saturated zone
- developing dilution factors, dispersion coefficients, etc.
- modifying existing codes and algorithms and including them into the LADTAP II code
- developing driver programs that connect or combine new algorithms or programs to the LADTAP II code
- developing appropriate data bases for the new algorithms or programs.

To achieve the objectives, the following subtasks will be performed.

SUBTASK 1. EXAMINATION OF THE REVISED HYDROLOGIC COMPONENTS OF THE LADTAP II CODE

The purpose of this subtask is to closely examine, for their appropriateness, each of the proposed pathways outlined in Subtasks 4 through 8. Because of the current structure of the LADTAP II code, the newly developed models addressing other hydrologic pathways (e.g., nontidal rivers, estuaries, etc.) may not interface with the LADTAP II code in the appropriate manner. LADTAP II may require modifications, if it is to correctly interface with each pathway.

The numerical algorithms describing contaminant movement within each pathway will be reviewed. Upon completion of this review, pathways consistent with the objectives outlined for the LADTAP II code will be identified, and these pathways will be coded (i.e., developed) and combined with the LADTAP II code. In addition, peripheral components that enhance the ease of application of the newly developed hydrologic components will be developed. These components include:

- algorithms for computing dilution factors, dispersion coefficients, etc., necessary in implementing the hydrologic components of the LADTAP II code
- data bases that are used for internal calculations
- driver programs that are used to connect or combine algorithms, programs, and/or data bases.

The level of effort for this subtask is estimated at two man-weeks.

SUBTASK 2. NONTIDAL RIVERS AND LAKES

Nontidal rivers refer to freshwater bodies with unidirectional flow in definable channels. Contaminants can be discharged into a river as a steady-state, continuous release or as a transient routine release that is batched and infrequent.

The application of the steady-state case will be restricted to those portions of the river removed from influences of the discharge. The flow is assumed to be uniform and approximately steady. Under these conditions, the dispersive transport in the flow direction may be considered negligible compared to advective transport. The flow will be divided into streamtubes and a program will be used to estimate the location of the streamtubes and appropriate dispersion factors. Variations in river-bottom topography and flow velocity also will be considered. The steady-state case will be described by Equations (1) through (8) as outlined in Regulatory Guide 1.113.

The application of the transient case will be restricted to a straight, rectangular channel corresponding to the instantaneous release of a finite quantity of contaminant from a vertical line source. Application of this case should be restricted to those portions of the river removed from the influence of the contaminant discharge point. The transient case will be described by Equations (9) and (10) as outlined in Regulatory Guide 1.113.

Lakes refer to major bodies of water occupying depressions within the earth's surface (e.g., lakes). Contaminants can be discharged along lakes as a transient routine release. The application of the transient case will be restricted to those portions of the near-shore zone of a water body removed from the influence of the discharge. When applied in the near-shore zone, the case should be not be considered during the time between wind-induced current reversals. The release will be from a vertical line source extending from the water surface to the bottom. The transient case will be described by Equations (19) and (20) as outlined in Regulatory Guide 1.113.

Key and Whelan (1980) provide some documentation for the steady-state and transient nontidal river conditions and for the transient lake condition. The codes outlined by Key and Whelan (1981) will have to be modified to conform with the LADTAP II code. The level of effort for developing and/or modifying the appropriate codes addressing the cases outlined under this subtask is estimated at 4 man-weeks.

SUBTASK 3. IMPOUNDMENTS

The following summary presents recommended changes to the impoundment reconcentration factor models of LADTAP II, as programmed in Strenge et al. (1985) and as presented in Simpson and McGill (1980) and Regulatory Guide 1.113 (U.S. NRC 1977b). The recommendations are based on equation derivations by Gene Whelan for this project. Complete derivations have been supplied for NRC review and are available upon request.

1) Plug-Flow Model - Equation (46) as presented in Regulatory Guide 1.113.

$$C/C_o = \exp\left[-\lambda V_T/Q_b\right] \tag{46}$$

represents only an approximate solution to the Plug-Flow Model case. The solution is an approximate one because

- the longitudinal flow discharge (Q_x) is assumed to be constant and equal to the blowdown discharge (Q_b) in the direction of the flow, and
- the evaporative flux (Q_E) is assumed to be negligible (this may be a valid assumption).

If the flow discharge is assumed to vary linearly in the direction of the flow by assuming that the evaporative flux is uniformly distributed over the pond (note that this is a very valid assumption), then an exact solution exists for the plug-flow case. An alternate solution to Equation (46) is

$$C/C_o = \left(\frac{Q_b}{Q_b + Q_E}\right)^{\left(\frac{\lambda V_T - Q_E}{Q_E}\right)} \tag{a}$$

where λ = decay rate and V_T = pond volume. If Q_E goes to zero, then the equation reduces numerically to Equation (46). In many cases, C/C_o will be approximately unity and the evaporative flux will be negligible.

2) Partially Mixed Model - Questions arise around the conceptualization of the Partially Mixed Model case. If the travel time through the Plug-Flow Model case is assumed as the ratio between the pond volume (V_T) and the blowdown and plant pumping rates (Q_b and Q_p, respectively), Equation (47), as outlined in Regulatory Guide 1.113, expresses the Partially Mixed Flow Model case. That is,

$$C_2/C_o = \frac{R}{(R+1)\exp\left[\left(\frac{R}{R+1}\right)\left(\frac{\ln 2}{\tau}\right)\right] - 1} \tag{47}$$

where $R = Q_b/Q_p$, $\tau = (\ln 2)(Q_b + Q_p)/(\lambda)(V_T)$, $C_o = Q_c/Q_b$, λ = decay rate, Q_c = contaminant release rate in Ci per second, and V_T = pond volume. The asymptotic forms of Equation (47) are not necessarily correctly expressed by Equations (45)* and (46) of Regulatory Guide 1.113. The Regulatory Guide investigates the limit of R as R goes to infinity and zero. It assumes that C_o and τ are constants and are not functions of Q_b and Q_p. By definition this assumption is incorrect. If Equation (47) is rewritten as (assuming Q_E is negligible):

$$C_2 = \frac{Q_C}{\left(Q_b + Q_p\right)\exp\left(\frac{\lambda V_T}{Q_b + Q_p}\right)^{-1}} \tag{b}$$

and Q_p and Q_b are now allowed to go to zero, then

$$\lim_{Q_p \to 0} \left(C_2\right) = \frac{Q_C}{Q_b \exp\left[\frac{\lambda V_T}{Q_b}\right]} \tag{c}$$

and

$$\lim_{Q_b \to 0} \left(C_2\right) = \frac{Q_C}{Q_p \exp\left[\frac{\lambda V_T}{Q_p}\right]} \tag{d}$$

The other cases (i.e., $Q_p \to \infty$ and $Q_b \to \infty$) are not considered as they are unrealistic. Note that Equations (c) and (46) are exactly the same, as they are based on the same assumptions and derivation. Equations (d) and (45) are <u>not</u> and <u>should not</u> necessarily be the same, as these equations are based on different assumptions and derivations.

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* $\frac{C_2}{C_o} = \frac{\tau}{\tau + \ln 2}$

In addition, Equation (46) is based upon the approximate solution for plug flow. If the exact solution as outlined by Equation (a) is used in the derivation of the Partially Mixed Model case, the equation replacing that of Equation (47) would be (assume Q_E is not negligible):

$$C_2 = \frac{\left(\frac{Q_C}{Q_b + Q_p + Q_E}\right)\left(\frac{Q_b + Q_p}{Q_b + Q_p + Q_E}\right)^{\left(\frac{\lambda V_T - Q_E}{Q_E}\right)}}{1 - \left(\frac{Q_p}{Q_p + Q_b + Q_E}\right)\left(\frac{Q_b + Q_p}{Q_b + Q_p + Q_E}\right)^{\left(\frac{\lambda V_T - Q_E}{Q_E}\right)}} \quad . \qquad \text{(e)}$$

By letting Q_b and Q_p go to zero, their importance can be analyzed.

$$\lim_{Q_p \to 0}\left(C_2/Q_C\right) = \left(\frac{1}{Q_b + Q_E}\right)\left(\frac{Q_b}{Q_b + Q_E}\right)^{\left(\frac{\lambda V_T - Q_E}{Q_E}\right)} \quad . \qquad \text{(f)}$$

If Q_E is negligible, then Equation (f) becomes numerically equivalent to

$$\lim_{\substack{Q_p \to 0 \\ Q_E \to 0}}\left(C_2/Q_C\right) = 1/Q_b \exp\left[\frac{-\lambda V_T}{Q_b}\right] \qquad \text{(g)}$$

and

$$\lim_{Q_b \to 0}\left(C_2/Q_C\right) = \frac{\left(Q_p / \left(Q_p + Q_E\right)\right)^{\left(\frac{\lambda V_T - Q_E}{Q_E}\right)}}{\left(Q_p + Q_E\right) - \left(Q_p\right)\left(\frac{Q_p}{Q_p + Q_E}\right)^{\left(\frac{\lambda V_T - Q_E}{Q_E}\right)}} \quad . \qquad \text{(h)}$$

If Q_E is negligible, then Equation (h) becomes numerically equivalent to

$$\lim_{\substack{Q_b \to 0 \\ Q_E \to 0}} C_2/Q_C = \frac{\exp\left[\frac{-\lambda V_T}{Q_p}\right]}{Q_p\left(1 - \exp\left[\frac{-\lambda V_T}{Q_p}\right]\right)} \quad . \tag{i}$$

Note that Equations (a) and (f) are the same (i.e., $C_o = Q_C/(Q_b + Q_E)$) as they are based on the same assumptions and derivations. The cases where $Q_p \to \infty$ and $Q_b \to \infty$ are not considered as they represent unrealistic cases.

Equation (47), as it relates to Equation (e), represents in effect the case where the plant pumping rate (Q_p) is negligible relative to that of the blowdown rate (Q_b). For the case where the plant pumping rate is equivalent to or larger than the blowdown rate (assuming $Q_E + Q_b + Q_p$ = constant), the significance of Q_p is not indicated by Equation (47) as it is in Equation (e). If Equation (e) is employed as opposed to Equation (47), the effects of the pumping rate are included. In most cases, the evaporative flux is negligible. Equation (e) becomes important when

- Q_E becomes significant, and
- $Q_p >> Q_b$.

The level of effort for modifying the impoundments section of the LADTAP II code is estimated at 1 man-week.

SUBTASK 4. GROUNDWATER

Groundwater movement generally occurs in two distinct zones: partially saturated and saturated zones. The partially saturated zone extends from the land surface down to the groundwater table. The saturated zone is everything below the groundwater table surface. The partially saturated zone will not be dealt with for the following reasons:

- The three-phase (i.e., solid, liquid, and gaseous) relationship that is prevalent in partially saturated zones is difficult and complex to model.

- Hydraulic properties (e.g., hydraulic conductivity) can vary greatly with small changes in the amount of water present.
- Dispersion coefficients are difficult to quantify due to the complex nature of the system.
- Neglecting contaminant dispersion and attenuation through the partially saturated zone generally represents a conservative estimate.

The saturated zone will be presented by point-source and/or horizontal area-source models. Application of these codes will be restricted to transient releases from a point and/or area source and to sites with a constant aquifer thickness and porosity, uniform flow field and soil characteristics, and no sinks or sources. Attenuation will be described by an equilibrium (i.e., partition or distribution) coefficient.

The groundwater pathway is not addressed by Regulatory Guide 1.113. Key and Whelan (1981) provide some documentation; the documentation and the respective codes will have to be modified to conform with the LADTAP II code. The level of effort employed for modifying and developing these codes is estimated at two man-weeks.

IV. REPORTING REQUIREMENTS

Throughout the period of performance of the project, the Task Leader will maintain close liaison with the Program Manager. Monthly internal reports will be prepared by the Task Leader to identify any problems and to show progress and variance. These monthly reports will be submitted by the fifth day of each month.

Upon completion of Subtasks 1 through 4, the Task Leader will prepare a Final Task Report to be submitted to the Project Manager. The Final Task Report will update the current documentation, as described by Strenge et al. (1985), describing the hydrologic components of the LADTAP II code. Much of the documentation for the hydrologic models will be based on currently available literature from NRC.

The report will be reviewed by Dr. Y. Onishi, Staff Engineer, Geosciences Research and Engineering Department; he will serve as a technical auditor.

Following the receipt of review comments from NRC staff, the Final Task Report will be finalized within a reasonable time span designated by the Project Manager. Publication of any material directly related to this task shall be approved by the sponsor.

V. PROJECT SCHEDULE

If the effort, as outlined herein, is accepted, the project schedule will have to be decided upon by the Project Manager and Task Leader.

VI. TIME AND COST ESTIMATES

The Task Leader proposes to conduct the work outlined in Subtasks 1 through 4 for an estimated period of five months, which includes time for submitting the Final Task Report, with an estimated funding level of $23,000. This funding level includes 9 man-weeks of work for the Task Leader and 2 man-days of work for Dr. Y. Onishi. The remaining funds cover additional expenses in the following areas: computer, QA requirements, secretarial and word processing work, graphics, task management, and duplicating.

VII. REFERENCES

Key, K. T., and G. Whelan. 1981. A Collection of Mathematical Models for Dispersion in Surface Water and Groundwater. NUREG-0868. Prepared for the U.S. Nuclear Regulatory Commission by Pacific Northwest Laboratory, Richland, Washington.

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Simpson, D. B., and B. L. McGill. 1980. User's Manual for LADTAP II - A Computer Program for Calculating Radiation Exposure to Man from Routine Release of Nuclear Reactor Liquid Effluents. NUREG/CR-1276, ORNL/NUREG/TDMC-1. Prepared for the U.S. Nuclear Regulatory Commission by Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Strenge, D. L. R. A. Peloquin, and G. Whelan. 1985. LADTAP II - Technical Reference and User's Guide. NUREG/CR-4013, PNL-5270. Prepared for the U.S. Nuclear Regulatory Commission by Pacific Northwest Laboratory. (Draft)