

NARAYANAN RAJENDRAN

*Vice President and Manager
Inhalation Toxicology Division
Life Sciences Group
IITRI (IIT Research Institute)*

Technical Areas

Generation, measurement, and characterization of test atmospheres for inhalation toxicology studies; therapeutic aerosol generation and monitoring for inhalation studies; cigarette smoke generation for inhalation studies; smoke aerosol characterization; bioaerosol generation and sampling; droplet evaporation; particle deposition studies in human respiratory tracts; dynamics of aerosol systems; high concentration dust measurement; mist suppression and dust explosions

Education

Ph.D., Engineering Sciences, State University of New York, 1977; M.S., Engineering Sciences, State University of New York, 1974; B.S., Mechanical Engineering, Madras University, India, 1969

Experience

IIT Research Institute, Inhalation Toxicology Division, Life Sciences Group: *Vice President*, since 2005; *Section Head*, Inhalation Toxicology Section, since 2003; *Manager*, since 1999; *Assistant Vice President*, 2000-2005; *Science Advisor*, 1993-1999; *Senior Engineer*, 1986-1993; *Research Engineer*, 1981-1986; *Associate Engineer*, 1977-1981; State University of New York, Buffalo: *Research Fellow*, 1975-1977; *Teaching Fellow*, 1972-1975

As Vice President and Manager, Dr. Rajendran is responsible for maintaining the financial and technical integrity of the Inhalation Toxicology Division's testing programs, supporting business development, preparing proposals to clients, and providing state-of-the-art inhalation exposure procedures. He currently manages several multi-million dollar projects including a multi-year testing program for industrial clients. As an Aerosol Scientist, Dr. Rajendran provides scientific input in the design and development of all study-specific test atmosphere generation and monitoring systems.

Since the early 1980s, Dr. Rajendran has been involved in solving test atmosphere generation and monitoring problems encountered in inhalation studies. He has worked since 1978 on a number of inhalation toxicology programs, including studies for the U.S. Environmental Protection Agency, a red phosphorus/butyl rubber obscurant smoke exposure study for the U.S. Army, and subchronic inhalation toxicity studies with 2-mercaptobenzimidazole (2-MBI), and vanadium pentoxide for the National Toxicology Program (NTP). For the 2-MBI studies, he devised a unique approach to aerosolize sticky powders, a very complex and difficult problem. Dr. Rajendran developed aerosol/vapor generation systems for nose-only inhalation toxicity studies conducted for pharmaceutical companies, which employed a powder dispenser, metered-dose inhalers, or flash evaporator.

In other completed studies, he devised techniques to generate highly dispersed aerosols from bulk powders including several metal compounds and viscous liquids and developed methods for *in situ* measurement of the aerosol concentrations and aerosol output from metered-dose inhalers.

In his university research, Dr. Rajendran examined the acoustic agglomeration of aerosols and theoretical modeling of aerosol deposition in the human respiratory tract.

Professional Affiliations

American Association of Aerosol Research

Awards

Listed in *American Men and Women of Science*; *Who's Who in the Midwest*

Publications, Presentations, and Patents

Author or coauthor of over 60 publications, abstracts, and presentations, and one patent in the fields of inhalation toxicology, developmental toxicity, particle deposition in the human respiratory tract, filtration of aerosols and acoustic agglomeration of aerosols.

1. Diffusional deposition of airborne particles in curved bronchial airways. *J. Aerosol Sci.*, **8**(3), 191-198 (1977). D. T. Shaw and N. Rajendran.
2. Deposition of bacterial aerosols on a round wedge nose wedge in the interception region. *J. Aerosol Sci.*, **8**(3), 199-204 (1977). D. T. Shaw, N. Rajendran, D. B. Taulbee, and K. W. Tu.
3. Acoustic aerosol agglomeration. Presented at the 51st Colloid and Surface Science Symposium, Grand Island, N.Y., June 19-22, 1977. D. T. Shaw, N. Rajendran, S. Patel, and M. T. Cheng.
4. Theoretical modeling of fine particle deposition in three-dimensional bronchial bifurcations. *Am. Ind. Hyg. Assoc. J.*, **39**(3), 195-201 (1978). D. T. Shaw, N. Rajendran, and N. S. Liao.
5. Transport effect on liquid therapeutic aerosols. Presented at the Powder and Bulk Conference, Philadelphia, PA, May 15-17, 1979. N. Rajendran and S. Katz.
6. Study of therapeutic aerosols. Presented at the 19th Annual American Industrial Hygiene Association Conference, Chicago, IL, May 27-June-1, 1979. N. Rajendran and S. Katz.
7. Application of acoustic agglomerators for emergency use in LMFBR plants. *Nucl. Sci. Eng.*, **70**, 127-134 (1979). N. Rajendran.
8. Acoustic precipitation of aerosol understanding wave conditions. *J. Aerosol Sci.*, **10**, 329-338 (1979). N. Rajendran, J. Wegrzyn, M. T. Cheng, and D. T. Shaw.
9. Acoustic agglomeration of aerosols. Presented at the Powder and Bulk Solids Conference, Chicago, IL, May 13-15, 1980. N. Rajendran.
10. Theoretical investigation of inlet characteristics of personal samplers. Presented at the 13th Aerosol Technology Meeting, Boston, MA, August 18-20, 1980. N. Rajendran.
11. Sampler inlet characteristics. Presented at and published in the proceedings of the ASME Symposium on Cotton Dust, October 7-8, 1980. N. Rajendran.
12. Liquid aerosols. Presented at the First American Association of Aerosol Research Annual Meeting, Santa Monica, CA, February 17-19, 1982. N. Rajendran.
13. Safe and efficient grease extractor. U.S. Patent. K. Otzen and N. Rajendran.
14. Grain dust measurement. Presented at Fine Particle Society Meeting, Hawaii, August 1983. J. D. Stockham and N. Rajendran.
15. Reliable techniques to measure grain dust. Presented at Pittsburgh Conference and Exposition, Atlantic City, NJ, March 5-8, 1984. J. D. Stockham and N. Rajendran.
16. Comparison of methods for measuring dust concentration. Presented at American Society of agricultural Engineers Winter Meeting, Chicago, IL, December 17-20, 1985. N. Rajendran and B. Moechnig.
17. Grain dust measurement techniques: An evaluation. *Trans. Am. Soc. Agr. Eng.*, **28**(6), 2030-2036 (1985). N. Rajendran and J. D. Stockham.

18. Grain dust measurements in active grain elevators. Proceedings of the ASTM Symposium on Industrial Dust Explosions at Pittsburgh, PA, June 10-12, 1986.
19. Emissions from locomotive brakes. Presented at Symposium on Friction Materials, Atlantic City, NJ, October 5-7, 1987. A. Anderson and N. Rajendran.
20. Subchronic inhalation toxicity study of 2-mercaptobenzimidazole aerosols. Presented at Society of Toxicology Annual Meeting, Miami, FL, February 1989. C. L. Gaworski, C. Aranyi, S. Vana, N. Rajendran, A. Hall, and K. Abdo.
21. High concentration dust measurement techniques. Presented at American Association of Aerosol Research Annual Meeting, Reno, NV, October 1989. N. Rajendran.
22. Prechronic inhalation toxicity studies of 2-mercaptobenzimidazole (2-MBI) in F344/N rats. *Fundam. Appl. Toxicol.*, **16**, 161-171 (1990). C. L. Gaworski, C. Aranyi, S. Vana, N. Rajendran, K. Abdo, B. S. Levine, and A. Hall, III.
23. Inhalation exposure of F344/N male rats to aerosol mixtures used as military obscurants. *J. Am. College Toxicol.*, **10**(5), 620 (1991). C. Aranyi, N. Rajendran, S. Vana, J. Bradof, R. Sherwood, J. Drummond, M. Tomlinson, B. Levine, R. Gibbons, and J. Dacre.
24. Inhalation exposure of laboratory rats to aerosol mixtures of fog oil and graphite for use as military obscurants. Presented at and published in the proceedings of Smoke/Obscurants Symposium XVI, Laurel, MD, April 14-16, 1992, p. 74. C. Aranyi, N. Rajendran, S. Vana, J. Bradof, J. Drummond, R. Sherwood, M. Tomlinson, J. Tepper, B. Levine, R. Gibbons, and J. Dacre.
25. Inhalation exposure of F344/N male rats to aerosol mixtures used as military obscurants. Presented at and published in the proceedings of the 13th Annual Meeting of the American College of Toxicologists, San Francisco, CA, October 22-24, 1992. *J. Am. College Toxicol.*, **12**(1), (1993). C. Aranyi, N. Rajendran, S. Vana, J. Bradof, R. Sherwood, J. Drummond, M. Tomlinson, B. Levine, R. Gibbons, and J. Dacre.
26. Subchronic nose-only inhalation toxicity study in rats with Atrovent HFC 134A formulation using an aerosol generation system with metered dose inhalers. *Toxicologist*, **45**, 102 (1996). N. Rajendran, J. Gerhart, S. Vana, D. Ball, T. MacGregor, F. Pack, R. Stoll, and C. Aranyi.
27. Fourteen-day inhalation toxicity study of N-ethyl-M-toluidine in rats. *Toxicologist*, **48**, 115 (1999). E. Stephens, N. Rajendran, D. Sullivan, and J. Gerhart.
28. Thirteen-week inhalation toxicity study of menthol cigarette smoke. *Food Chem. Toxicol.*, **25**, 683-692 (1997). C. L. Gaworski, M. M. Dozier, J. M. Gerhart, N. Rajendran, C. Aranyi, L. H. Brennecke, and J. D. Heck.
29. Cigarette smoke vapor-phase effects in the rat upper respiratory tract. *Inhalation Toxicology*, **10**, 857-873 (1998). C. L. Gaworski, M. M. Dozier, S. Eldridge, R. Morrissey, N. Rajendran, and J. M. Gerhart.
30. Toxicologic evaluation of flavor ingredients added to cigarette tobacco: 13-week inhalation exposures in rats. *Inh. Toxic.*, **10**, 357-381 (1998). C. L. Gaworski, M. M. Dozier, J. D. Heck, J. M. Gerhart, N. Rajendran, R. M. David, L. H. Brennecke, and R. Morrissey.
31. Toxicologic evaluation of diammonium phosphate added to cigarette tobacco and reconstituted leaf: 13-week smoke inhalation studies in rats. Presented at the 55th Tobacco Science Research Conference, Greensboro, NC, September 9-12, 2001. M. Misra, J. D. Heck, C. L. Gaworski, and N. Rajendran.
32. Validation of a new smoking machine for rodent inhalation studies. Presented at the 55th Tobacco Science Research Conference, Greensboro, NC, September 9-12, 2001. S. Appleton, G. R. Krautter, J. H. Lauterbach, and N. Rajendran.
33. Validation of a nose-only rodent inhalation smoking protocol. Presented at the 55th Tobacco Science Research Conference, Greensboro, NC, September 9-12, 2001. S. Appleton, G. R. Krautter, J. H. Lauterbach, R. Morrissey, and N. Rajendran.
34. Toxicologic evaluation of humectants added to cigarette tobacco: 13-week smoke inhalation study of glycerine and propylene glycol in Fischer 344 rats. *Inh. Toxic.*, **14**, 1135-1152 (2002). J. D. Heck, C. L. Gaworski, N. Rajendran, and R. Morrissey.

35. *In utero* exposure to 1R4F reference cigarette smoke: Evaluation of developmental toxicity, *Toxicol. Sci.*, **75**, 134-147 (2003). E. L. Carmines, C. L. Gaworski, A. S. Faqi, and N. Rajendran.
36. *In utero* and lactation exposure of rats to 1R4F reference cigarette mainstream smoke: Effect on prenatal and postnatal development. *Toxicol. Sci.* **79**, 157-169 (2004). C. L. Gaworski, E. L. Carmines, A. S. Faqi and N. Rajendran.
37. Toxicological evaluation of spearmint oil added to tobacco: *In Vitro* and *In Vivo* Tests. Presented at the 45th Annual Meeting of Society of Toxicology, San Diego, CA, March 5-9, 2006. M. Misra, R.D. Leverette, J.T. Hamm and N. Rajendran.
38. Histological alterations in male A/J mice following nose-only exposure to tobacco smoke. *Inhal. Toxicol.*, **19**(5), 405-18 (2007). J. T. Hamm, S. Yee, N. Rajendran, R. L. Morrissey, S. J. Richter, and M. Misra.
39. Evidence for carbon monoxide as the major factor contributing to lower fetal weights in rats exposed to cigarette smoke. *Toxicol. Sci.*, **83** (2008). E. L. Carmines and N. Rajendran.
40. Effect of filtration by activated charcoal on the toxicological activity of cigarette mainstream smoke from experimental cigarettes. *Inhalation Toxicology*, **21**(8): 688-704 (2009). C. L. Gaworski, H. Schramke, J. Diekmann, T.J. Meisgn, F. Tewes, D. Veltel, P.M. Vanscheeuwijck, N. Rajendran, M. Muzzio, H.J. Haussmann.
41. Establishment of a Swiss Webster Mouse model of pneumonic plague to meet essential data elements under the animal rule. *Clin. Vaccine Immunol.*, **19**(4), 468-476 (2012). P. Fellows, W. Lin, D. Detrisac, S-C Hu, N. Rajendran, B. Gingras, L. Holland, J. Price, M. Bolanowski, and R.V. House.
42. Toxicologic Evaluation of Tungsten: 28-day inhalation study of tungsten blue oxide in rats. *Inhalation Toxicology*, **24**(4): 985-994 (2012). N. Rajendran, S-C. Hu, D. Sullivan, M. Muzzio, C. J. Detrisac and C. Venezia.

Abstracts and Poster Presentations

1. Subchronic inhalation toxicity study of 2-mercaptobenzimidazole (2-MBI) aerosols. *Toxicologist*, **9**(1) (1989). C. L. Gaworski, C. Aranyi, S. Vana, N. Rajendran, A. Hall, III, and K. M. Abdo.
2. Inhalation exposure of F344/N male rats to aerosol mixtures used as military obscurants. Poster presented at the 12th Annual Meeting of the American College of Toxicologists, Savannah, GA, October 20-23, 1991. C. Aranyi, N. Rajendran, S. Vana, J. Bradof, R. Sherwood, J. Drummond, M. Tomlinson, B. Levine, R. Gibbons, and J. Dacre.
3. Inhalation exposures to vanadium pentoxide aerosols in mice: 14-day immunotoxicity and 13-week toxicity studies. *Toxicologist*, **13**(1), 47 (1993). C. Aranyi, D. Kirkpatrick, N. Rajendran, S. Vana, R. House, R. Sherwood, P. Thomas, M. Tomlinson, W. Moorman, and J. Roycroft.
4. Subchronic inhalation toxicity of vanadium pentoxide aerosols in rats. *Toxicologist*, **13**(1), 81 (1993). D. Kirkpatrick, N. Rajendran, S. Vana, J. S. Tepper, M. Tomlinson, W. Moorman, J. Roycroft, and C. Aranyi.
5. Aerosol generation method for dispersing highly cohesive powder. Poster presented at the 12th Annual Meeting of the American Association for Aerosol Research, Oak Brook, IL, October 11-15, 1993. N. Rajendran, S. Vana, C. Aranyi, and K. Abdo.
6. Local and systemic humoral response in rats exposed to mainstream cigarette smoke as assessed by a plaque-forming cell assay. 9th annual symposium of the Foundation of Immunotoxicology, Virginia Beach, VA (1994). M. M. Dozier, C. L. Gaworski, J. D. Heck, H. V. Ratajczak, N. Rajendran, and P. T. Thomas.
7. Metered dose inhaler based aerosol generation system. Poster presented at the Fourth International Aerosol Conference, Los Angeles, CA, August 29-September 2, 1994. N. Rajendran, S. Vana, J. McIntyre, and C. Aranyi.
8. Nose-only inhalation exposure to ipratropium bromide lactose inhalation blend in Sprague-Dawley rats. Poster presentation at the International Congress of Toxicology VII, Seattle, WA, July 2-6, 1995. N. Rajendran, W. D. Johnson, D. J. Ball, F. D. Pack, R. E. Stoll, and C. Aranyi.

9. A 13-week inhalation toxicity study of menthol cigarette smoke. Poster presentation at the International Congress of Toxicology VII, Seattle, WA, July 2-6, 1995. C. L. Gaworski, M. M. Dozier, J. D. Heck, J. M. Gerhart, N. Rajendran, C. Aranyi, and L. H. Brennecke.
10. Thirteen-week vapor inhalation study of Dow-Corning OS-120 in rats. *Toxicologist*, **36**(1) Part 2: March 1997, A1395, p. 275. W. H. Siddiqui, N. Rajendran, J. M. Gerhart, and S. A. Martin.
11. Rodent respiratory tract lesions associated with short-term exposure to whole cigarette smoke or its vapor. Presented at the Sixth International Inhalation Symposium, Hannover, Germany, 1997. C. L. Gaworski, M. M. Dozier, J. M. Gerhart, N. Rajendran, C. Aranyi, S. R. Eldridge, and R. Morrissey.
12. Twenty-eight-day nose only inhalation toxicity study of resorcinol bis-diphenylphosphate in rats. *Toxicologist*, **42**(1) Part 2: March 1998, A279, p. 57. W. D. Johnson, N. Rajendran, R. I. Freudenthal, R. T. Henrich, and C. Aranyi.
13. Comparison of the delivery efficacy of three inhalation exposure methods in beagle dogs. *Toxicologist*, **42**(1) Part 2: March 1998, A1241, p. 252. J. Gerhart, N. Rajendran, B. Harder, D. Sullivan, I. Shorr, and L. McDonald.
14. Acute inhalation assessment of hydrocinnamoyl chloride in rats. *Toxicologist*, **42**(1) Part 2: March 1998, A1254, p. 254. E. Stephens, N. Rajendran, R. Leonatti, S. Garthwaite, J. Gerhart.
15. Fourteen-day inhalation toxicity study of n-ethyl-m-toluidine in rats. *Toxicologist*, **48**(1-S): March 1999, 543, p. 115. E. Stephens, N. Rajendran, D. Sullivan, and J. Gerhart.
16. Toxicologic evaluation of diammonium phosphate added to cigarette to cigarette tobacco and reconstituted leaf: 13-week smoke inhalation study in rats. Presented in 55th Tobacco Science Research Conference, Greensboro, NC, 2001. M. Misra, J. D. Heck, C. L. Gaworski, and N. Rajendran.
17. Validation of a new smoking machine for rodent inhalation studies. Presented in 55th Tobacco Science Research Conference, Greensboro, NC, 2001. S. Appleton, G. R. Krautter, J. H. Lauterbach, and N. Rajendran.
18. Validation of a nose-only rodent inhalation smoking protocol. Presented in 55th Tobacco Science Research Conference, Greensboro, NC, 2001. S. Appleton, G. R. Krautter, J. H. Lauterbach, and N. Rajendran.
19. Diammonium phosphate employed as a cigarette ingredient: 13-week cigarette smoke inhalation study in the rat. *Toxicologist*, **66**(1-S): March 2002, 1311, p. 268. M. Misra, J. D. Heck, C. L. Gaworski, N. Rajendran, and R. L. Morrissey.
20. *In utero* and lactational exposure to 1R4F cigarette smoke: Effects on neonatal development, growth and neurobehavior in the offspring rats. *Toxicologist*, **72**(1-S): March 2003, 363, p. 75. C. L. Gaworski, A. S. Faqi, N. Rajendran, and E. L. Carmines.
21. Qualification of a nose-only inhalation exposure system for inhalation challenge of *Yersinia pestis in vivo*. Presented at the Aerobiology in Biodefense III Symposium, Cumberland, MD, July 13-16, 2009. S-C. Hu, W. Lin, N. Rajendran, P. Fellows, M. Bolanowski, and L. Holland.
22. Development of a bioaerosol model for pneumonic plague in Swiss Webster mice. Presented at the Aerobiology in Biodefense III Symposium, Cumberland, MD, July 13-16, 2009. W. Lin, S-C. Hu, N. Rajendran, B. Gingras, L. Holland, C. Detrisac, M. Bolanowski, and P. Fellows.
23. Acute inhalation toxicity studies with vanadium trioxide (V₂O₃), vanadium tetroxide (V₂O₄), vanadium pentoxide (V₂O₅) and vanadyl sulfate (VOSO₄). Society of Toxicology Annual Meeting, San Francisco, CA, March 14, 2012, Abstract. A. I. Nikiforov, D. Sullivan, N. Rajendran, S-C. Hu, L. C. Fisher, and J. A. MacGregor.