SPECIAL REPORT 281

Transmission Pipelines and Land Use

A Risk-Informed Approach

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

the axes that define the limits of acceptable regions. For example, one could try to define on the net public benefits axis the limit of consequences that would be deemed unacceptable, however small the possibility of initiating failure. Similarly, from an initial scoping study for various pipelines and scenarios, one could try to define a limit on the fear factor that would be considered prohibitive. The problems encountered in seeking permission to transport spent nuclear fuel to a geologic repository demonstrate the relevance of this factor in a political setting in which such decisions are made.

In assessing likelihood, a fundamental issue is the metric to be used. For example, the probability of failure per unit length of pipeline or volume transported in a pipeline is very low, and safety measured in this way exceeds, by far, that of all other modes. However, for the pipeline system as a whole, there are about 300 accidents per year, which is not negligible, especially from the point of view of those who are adversely affected.

One approach may be to use a hierarchy that is based on the magnitude of potential consequences. At the upper end of the range of consequences, practices could be consistent with those for LNG storage tanks and other chemical plant facilities, and at the lower end more effort could be placed on prevention through inspection and monitoring programs, such as those already in place (e.g., Common Ground Alliance one-call systems).

Incidentally, the common practice of obtaining a measure of risk by multiplying probabilities and consequences is, in general, not adequate. One reason for the preference for the triplet (see Figure 3-1) is that a risk number alone does not distinguish a high-consequence, low-probability event from a low-consequence, high-probability event. In contrast, applying the scenario-likelihood-consequence approach provides all the key ingredients about risk necessary to inform decisions. For example, the loss of 10 lives (consequence) every 100 years (probability) is not the same as the loss of 100 lives every 1,000 years, even though in both cases the product of the two factors gives one-tenth of a life per year. Another reason is that the triplet definition is amenable to conveying levels of confidence in such estimates. These are also crucial, especially when multiple interests are involved, as is the case here. For example, a probability estimate that is expressed with a 90 percent confidence is certainly more reliable (it means that such an estimate would turn out to be correct for 90 percent of the time histories to which it pertains) than one expressed as a "best estimate" value. A 90 percent estimate is said to be conservative, and of course a 99 percent estimate is even more conservative.

Ultimately, judgment also has to come into play to balance value systems and conflicting forces. Again, all this requires sound technical work and a deliberate, consultative process with ample input from representative stakeholders, as discussed below in the section on risk communication.

PROBABILITY AND UNCERTAINTY

The role of logic and probability theory mentioned above is in decomposing complex, hard-to-characterize events into simpler events, to the degree deemed appropriate. This aspect of risk assessment is well founded and well developed, especially for pipeline risks, because those risks do not significantly involve complexity. "Complexity" refers to emergent system behavior—that is, behavior that is not a combination of the individually characterized behaviors of the system's presumed (superficially identifiable) parts. Thus, the success of pipeline risk assessment rests on defining the probabilities of component parts, and to a major extent this means the probabilities of initiating events.

For physical events, these probabilities can be defined with reasonable acceptability. For external events, empirical evidence is available that appears to be stable over many years and thus is acceptable for use in such assessments. Only the terrorism threat presents an intangible factor that has to be taken into account, perhaps at the upper end of the hierarchy mentioned above. The situation for internal events is mixed in that pipelines at different stages of their lifetime, under different conditions and maintenance and inspection procedures, present different kinds of challenges. Perhaps a hierarchical approach is needed here too, from well-characterized and hence more predictable cases to those so ill-defined that almost nothing can be said about them with any degree of certainty.

A robust treatment must distinguish between random and knowledge-type uncertainty (see Figure 3-3) and must express the confidence

sociated likelihood): (*a*) third-party damage, (*b*) corrosion, (*c*) design, and (*d*) incorrect operations. These four indexes score the probability and importance of all factors that increase or decrease the risk of a pipeline failure. The indexes are summed. The last portion of the assessment addresses the potential hazards, their probabilities of occurring, and their consequences. The consequence factor begins at the point of pipeline failure, called the leak impact factor. The leak impact factor is the sum of the product hazards divided by the dispersion factor.

This basic model can be expanded to include other modules such as the cost of service interruption, distribution systems, offshore pipelines, environment, failure adjustment, leak history adjustment, sabotage, and stress.

Consequence Model (C-FER Model)

C-FER Technologies developed a model that examines isometric thermal radiation distances to determine a burn radius and a 1 percent fatality radius from a natural gas pipeline break. An assumption of this model is that risk can be expressed as the product of failure probability and failure consequences, and reliability is the complement of failure probability. Probability of failure and consequence calculations are conducted by using two C-FER software programs—PIRAMID, which is used to optimize maintenance and inspection decisions, and PRISM, which is used to conduct pipeline reliability analyses (Zimmerman et al. 2002). The model incorporates three factors: a fire model that relates the gas release to the intensity of the heat, a model that provides an estimate of the amount of gas being released as a function of time, and a heat intensity threshold. The model can be used to determine a zone of impact for a pipeline fire. The equation used in the model relates the diameter and operating pressure of a pipeline to the size of the affected areas, assuming a worst-case failure event (Stephens 2000). The model can also be used to determine how the intensity of heat changes with the distance from the fire. From the model, "circles" around a pipeline fire that have equal levels of thermal radiation can be calculated. (In fact, the distance of equal thermal radiation from a pipeline fire may not be circular, depending on the nature of the gas discharge, obstructions of the jet of flowing gas, and delays in ignition. For example, the gas coming out of a ruptured pipe may be discharged in a particular direction or upward from the surface depending on the direction of the jet of flowing gas.)

C-FER calculates the degree of harm to people due to thermal radiation by using a model that relates the potential for burn injury or fatality to the thermal load received. A 30-second exposure time is assumed for people exposed to the fire in the open. In this interval, it is assumed that an exposed person will remain in fixed position for between 1 and 5 seconds (presumably to understand what is happening and react) and then run at 5 miles per hour in the direction of shelter. It is further assumed that a person would find a sheltered location within 200 feet of his or her initial position. It is offered that the heat flux that will cause burn injury is between 1,000 and 2,000 Btu/h/ft^2 (3.2 and 6.3 kW/m^2), depending on the burn injury criterion (e.g., time to blister). The threshold level of heat flux for fatal injury is determined when the chance of mortality is 1 percent; that is, 1 in 100 people directly exposed to this thermal load would not be expected to survive. This heat flux is calculated to be 5,000 Btu/h/ft^2 (15.8 kW/m^2).

C-FER also calculates a lower bound reliability curve based on the probability of a fatality or injury of an individual standing on the centerline of a pipeline. The third calculation is the cumulative frequency of casualties along the length of a pipeline system, called the FN curve. [See Harris and Acton (2001) for more information on these calculations.]

C-FER models the thermal load on wooden structures leading to ignition and fire. One calculation shows that 5,000 Btu/h/ft^2 (15.8 kW/m^2) would correspond to ignition in the presence of a flame source in approximately 20 minutes. It calculates that spontaneous ignition at this level of thermal radiation would not occur.

On the basis of these thermal radiation levels, C-FER calculates the radius of a hazard area as a function of pipeline size (diameter) and operating pressure. The graph of hazard area radius versus maximum operating pressure is shown in Figure D-1. A 36-inch-diameter pipeline operating at a maximum pressure of 1,000 pounds per square inch would have a hazard area radius of 750 to 800 feet. A 6-inch-diameter pipeline operating at less than 500 pounds per square inch would have a hazard area radius of less than 100 feet.

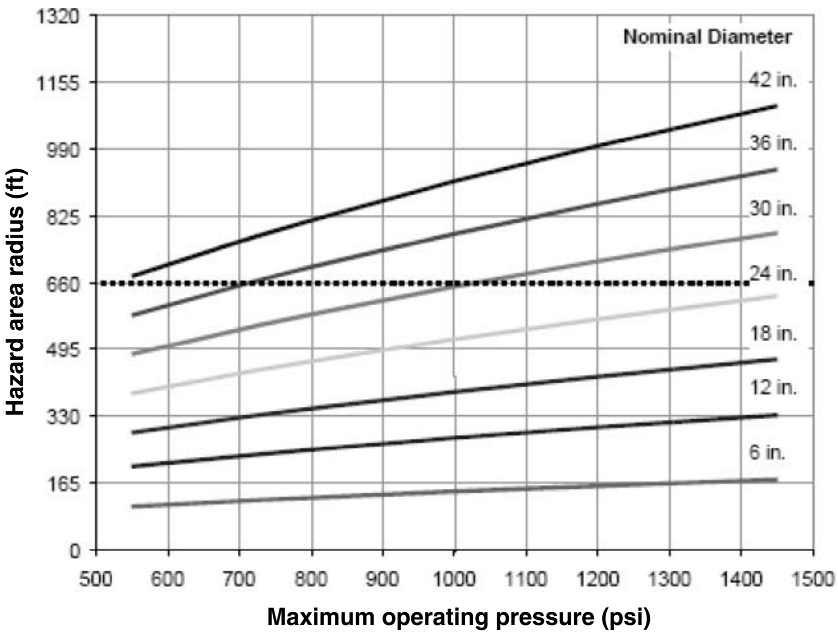

FIGURE D-1 Proposed hazard area radius as a function of line diameter and pressure. (SOURCE: Stephens 2000.)

By using the approach in C-FER's report, it would be possible to calculate hazard area distances for a variety of hazard scenarios involving more hardened structures and different accident scenarios.

PipeView Risk

PipeView Risk is a pipeline risk assessment program that assists pipeline operators in evaluating the current condition of their pipelines and identifying sections of higher risk in order to prioritize maintenance programs (Kiefner & Associates and M. J. Harden Associates 2004). PipeView Risk uses a relative risk ranking model. The analyses are performed by evaluating the physical pipeline attributes (e.g., diameter, grade, and wall thickness) in an algorithm that models the relationship between them. PipeView Risk is designed to be geographic information system (GIS) compatible by starting with an Integrated Spatial Analysis Techniques

(ISAT) database—a family of applications that integrate information from many sources including GIS; the Global Positioning System; pipeline maps; and other operating, monitoring, and maintenance data. The ISAT project was begun at the Gas Research Institute in the mid-1990s.

SUMMARY

A number of risk assessment methods are being used by the pipeline industry to prioritize risk mitigation actions. Regulatory agencies in the United States and abroad have developed risk-based regulations and criteria for safe operation of pipelines. While the risk assessment methodologies in use allow scarce resources to be focused on mitigation of the highest-risk items by emphasizing a single risk number, they do not adequately characterize all the dimensions of risk. A broader characterization of risk, as outlined in Chapter 3, will enable state and local policy makers, with input from stakeholders, to make land use decisions in a systematic manner.

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Study Committee Biographical Information

Don E. Kash, *Chair,* is Hazel Professor of Public Policy in the Department of Public Affairs at George Mason University. He is also guest professor at the Research Academy for 21st Century Development, Tsinghua University, Beijing. He received B.A., M.A., and Ph.D. degrees in political science at the University of Iowa. He was professor of political science at the University of Oklahoma from 1970 to 1991. From 1978 to 1981, Dr. Kash was Chief of the Conservation Division at the U.S. Geological Survey, which was responsible for regulating energy and mineral development on the Outer Continental Shelf (OCS), federal, and Indian lands. The division's responsibilities ranged from economic evaluations of minerals before leasing through establishing the standards for and regulating all of the steps from exploration through development and production to royalty collection. While he was division chief, the organization launched a new centralized royalty collection system, was reorganized, and implemented the regulations for OCS oil and gas operations required by the 1978 Outer Continental Shelf Lands Act Amendments. Dr. Kash has chaired numerous committees including the Marine Board Committee on Lightering; the 1995–1996 Advisory Panel on Technologies to Protect Fish at Dams, the 1994–1995 Advisory Panel on Advanced Automotive Technologies Project, the 1994 Workshop on Global Communications, and the 1991 Workshop on Alaska–California Subsea Water Pipeline for the Office of Technology Assessment; and the Cross-Disciplinary Engineering Research Committee of the National Research Council from 1986 through 1988. In addition, he has served as a member of numerous committees including the Selection Committee, Critical Technologies Institute Science and Engineering Fellows Program, American Association for the Advancement of Science, 1993–1994; the Committee on Transportation Research Centers, Transportation Research Board, National Research Council, 1992–1993; the Committee on New Technology and Innovation in Building, National Research Council, 1990–1992; the Panel on Oil and Gas Development in Hostile Offshore Environments for the Office of Technology Assessment, 1983–1985; and the Marine Board, 1974–1977 and 1985–1988. A Fellow of the American Association for the Advancement of Science, Dr. Kash has also published extensively in the fields of science technology and public policy, energy policy, and policy analysis.

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Raymond J. Burby is the Director of the Ph.D. Program in the Department of City and Regional Planning at the University of North Carolina at Chapel Hill. Dr. Burby teaches courses in land use and environmental planning, development impact assessment, development management, sustainable cities, hazard mitigation, and research methods. He is a fellow of American Institute of Certified Planners and is a member of numerous professional organizations. Dr. Burby is a former coeditor of the *Journal of the American Planning Association,* has authored or edited 14 books, and has published extensively in planning and policy journals including *Journal of the American Planning Association, Journal of Planning Education and Research, Journal of Policy Analysis and Management, Land Economics,* *Environmental Management*, and *Journal of Environmental Planning and Management.* He is currently principal investigator on a study of urban growth boundaries funded by the National Science Foundation. Dr. Burby received an A.B. degree from the George Washington University and M.R.P. and Ph.D. degrees from the University of North Carolina.

Cynthia Jensen Claus, attorney-at-law, lives and works in Lawrence, Kansas. By appointment of Governor Bill Graves, Ms. Claus served from 1997 to 2003 on the Kansas Corporation Commission, the agency having state regulatory oversight of public utilities (including telecommunications, electricity, natural gas, and water), pipeline safety, transportation, and the production of crude oil and natural gas. During her tenure as Commissioner, she served as the official representative of Kansas to the Interstate Oil and Gas Compact Commission, where she was a member of the Legal and Regulatory Affairs Committee and served on the Steering Committee, the Resolutions Committee, and the Finance Committee. She was also a member of the National Association of Regulatory Utility Commissioners, serving on the Finance and Technology Committee and the Telecommunications Committee. Before her service on the Kansas Corporation Commission, she provided in-house legal services for 16 years (including 5 years as chief counsel) to ARCO Pipe Line Company, a regulated cross-country oil pipeline company. She served as a member of the State Affairs Committee of the Association of Oil Pipe Lines from 1989 to 1995 and as Chairman of the Pipeline Committee of the Texas Mid-Continent Oil and Gas Association from 1994 to 1995. Ms. Claus has an undergraduate degree from the University of Kansas and a law degree from the University of Kansas School of Law, where she was elected to Order of the Coif. She served as a member of the Board of Governors for the Law Society for the University of Kansas School of Law from 1983 to 1985. She also served as the Municipal Judge for the cities of Independence and Cherryvale, Kansas, from 1978 to 1979. In 2003, she was appointed to the American Arbitration Association's panel of neutrals.

Geraldine E. Edens is Office Counsel at McKenna, Long & Aldridge, LLP. Before taking this position, she was Special Litigation Counsel to Cadwalader, Wickersham & Taft's Environmental Law Group. Dr. Edens practices in areas involving environmental litigation, regulatory matters, and issues concerning law and science, and she has performed environmental audits and reviews for a variety of corporate clients in the chemical manufacturing and mining industries. She counsels clients on environmental compliance, the law and science of chemical regulation, toxic tort health claims [asbestos, boron, polychlorinated biphenyls, lead, benzene, methyl tertiary butyl ether (MTBE), etc.], and a wide variety of Clean Air Act issues. Dr. Edens has a broad base of litigation experience, including service as lead counsel on behalf of an intervenor-defendant in a National Environmental Policy Act case challenging a federal grant of a right-of-way for an interstate pipeline and challenging the authority of the Department of Transportation to ban the transport of MTBE in an interstate pipeline. Dr. Edens graduated from the University of Miami School of Law magna cum laude and Order of the Coif, where she was a member of the *University of Miami Law Review.* She has a Ph.D. in education from the University of Florida and M.S. and B.S. degrees from the University of Miami. Dr. Edens is a member of the District of Columbia and Maryland Bars. She is coauthor of two chapters, "Federal Environmental Liability" and "Indoor Air Quality," in *Environmental Aspects of Real Estate Transactions,* and the chapter "Indoor Air Quality" in *Environmental Law Practice Guide: State and Federal Law.* Before joining Cadwalader, Dr. Edens was a professor at the University of Miami, where she was a member of the graduate school faculty.

William L. Halvorson is a research ecologist with the U.S. Geological Survey at the Sonoran Desert Research Station and a professor in the School of Natural Resources, both at the University of Arizona. His research interests include vegetation ecology of arid and semiarid regions, species distribution and diversity, community structure, restoration and management of natural ecosystems, and landscape ecology. He has a bachelor's degree from Arizona State University, a master's degree from the University of Illinois, and a Ph.D. from Arizona State University. He is a member of the California Botanical Society and the Ecological Society of America and serves on the Board of Directors of the Society for Ecological Restoration.

Robert L. Malecki is principal owner of Malecki Consulting, LLC. He provides consulting services to energy-sector clients in the northeastern United States, with an emphasis on environmental assessment and permitting, government and community cooperation, approval acquisition, and design and implementation of environmental protection techniques. He recently retired from the New York State Electric and Gas Company. During the last 10 of his 33 years there he was responsible for environmental planning, regulatory approvals, licensing, construction and operational impact mitigation, compliance, and hazardous waste disposal. Mr. Malecki holds a B.S. in forest science from Pennsylvania State University and has undertaken graduate studies on environmental impact assessment at the College of Environmental Science and Forestry at the State University of New York, Syracuse. He also has taken graduate studies in the management development program at the University of Michigan.

James M. Pates has served since 1986 as the City Attorney of the City of Fredericksburg, Virginia, in which capacity he is responsible for all of the civil legal affairs of the city, including litigation, legislation, and a wide variety of commercial, real estate, land use, and environmental transactions. Since 1990, he has helped lead a national effort by a coalition of environmental, state and local government, and public interest groups to improve pipeline safety. He is one of the founders and currently serves as Vice President of the National Pipeline Reform Coalition. He has testified before Congress on various pipeline safety bills and has authored local, state, and federal legislation aimed at increasing the role of state and local governments in pipeline safety. Mr. Pates is the author of two papers on pipeline safety and the producer of a 1996 public service video, "Out of Sight, Out of Mind: What Every Local Government Should Know About Pipeline Safety." Before taking his current position, he served as legislative counsel to the Subcommittee on Commerce, Consumer, and Monetary Affairs of the Committee on Government Operations, U.S. House of Representatives, and later as government relations counsel for a national trade association in Washington, D.C. Mr. Pates is a magna cum laude graduate of Amherst College and a graduate of the University of Virginia Law School.

Richard A. Rabinow became President of The Rabinow Consortium, LLC, following his retirement from ExxonMobil in 2002 after 34 years of service. At the time of his retirement, Mr. Rabinow was the president of

ExxonMobil Pipeline Company (EMPCo), a position he had held at EMPCo and its predecessor, Exxon Pipeline Company, since 1996. Before that, Mr. Rabinow held the position of Vice President and Lower 48 Manager of Exxon Pipeline Company. He received a B.S. degree in engineering mechanics from Lehigh University and M.S. degrees in mechanical engineering and management, both from the Massachusetts Institute of Technology. During 1994 and 1995, Mr. Rabinow held the position of Senior Vice President, Integrity and Compliance Projects, while on loan to the Alyeska Pipeline Service Company in Anchorage, Alaska. He serves as Vice President of the Board of Trustees of the Houston Arboretum and Nature Center. He is a former member of the American Petroleum Institute and the Association of Oil Pipe Lines and has been a member of the Trans Alaska Pipeline System Owners Committee.

Narasi Sridhar is a Program Director in the Mechanical and Materials Engineering Division at Southwest Research Institute, where he has worked since 1989. At Southwest Research Institute, he has been managing projects related to the licensing of engineered barrier system designs for high-level nuclear waste disposal, safety evaluation of processes to remediate liquid radioactive wastes at Hanford, corrosion mitigation pertaining to gas pipelines, corrosion prediction for chemical process industries, marine corrosion, and aircraft corrosion. Before joining Southwest Research Institute, he was active in the chemical process, pulp and paper, and oil and gas industries. He has more than 20 years of experience in materials development, electrochemistry, and corrosion, and he has been involved in the development of nickel-, cobalt-, copper-, and iron-base alloys for more than 15 years. Dr. Sridhar received a B.S. degree in metallurgy from the Indian Institute of Technology in 1975, an M.S. degree in materials engineering from Virginia Polytechnic Institute and State University in 1977, and a Ph.D. in metallurgical engineering from the University of Notre Dame in 1980. He has published more than 70 papers and has contributed chapters to several handbooks on corrosion and corrosion-resistant alloys. He is a member of the Electrochemical Society, NACE International, ASM International, American Society for Testing and Materials, and the Board of Editors of the journal *Corrosion.* In recognition of his outstanding contributions to corrosion in several industries, he received a NACE Technical Achievement award.

Theofanis G. Theofanous, NAE, is Professor and Director of the Center for Risk Studies and Safety at the University of California, Santa Barbara. He received a Ph.D. from the University of Minnesota and a B.S. degree from the National Technical University, Athens, Greece, both in chemical engineering. From 1974 through 1985, he was a professor and founding director of the Nuclear Reactor Safety Laboratory at Purdue University. Dr. Theofanous is a member of the National Academy of Engineering, a fellow of the American Nuclear Society, and a foreign member of the Ufa Branch of the Russian Academy of Sciences. Among his other honors are the E. O. Lawrence Presidential Medal and an Honorary Doctorate from the University of Laapeenrantaa, Finland. He has published extensively and has received numerous best paper awards. His technical interests focus on multiphase transport phenomena and risk assessment and management in complex technological and environmental systems. He studies methodological issues in treating uncertainty in risk assessments and basic multiphase flow physics, and he works to integrate these basic aspects toward understanding and optimizing system behavior, assessing risks, and improving safety.

Theodore L. Willke is President of TLW Solutions, Inc., a consulting firm specializing in risk management and the application of new and emerging oil and gas pipeline technology. He is a lecturer and faculty advisor in the H. John Heinz III School of Public Policy and Management at Carnegie Mellon University. Dr. Willke received B.S. degrees in astronautical engineering and engineering science from the U.S. Air Force Academy, an S.M. in nuclear engineering from the Massachusetts Institute of Technology, an M.B.A. from the University of Dayton, and a Ph.D. in industrial and systems engineering from the Ohio State University. From 1997 to 2001, he was Director and Chief Executive Officer of Carnegie Mellon Research Institute. Dr. Willke is a member and has served as chair of a pipeline safety advisory committee for the U.S. Secretary of Transportation, Technical Pipeline Safety Standards Committee, Office of Pipeline Safety. He also served as chair of the International Committee on Pipeline Repair and Rehabilitation representing 22 countries for the International Gas Union. Dr. Willke served as Vice President in charge of pipeline, distribution, and environment and safety technology research and development at the Gas Research Institute, where he worked in various capacities from 1984 through 1997. He managed the design and construction of two major pipeline test facilities—the Metering Research Facility in San Antonio and the Pipeline Simulation Facility in Columbus, Ohio. He developed and obtained regulatory approval for a new pipeline repair technology and introduced a van-mounted natural gas leak detector to the market. Dr. Willke was chair of the Pittsburgh International Science and Technology Festival and of the technology committee of the New Idea Factory for County Executive Jim Roddy. He is a previous board member of the Ben Franklin Technology Center of Western Pennsylvania and a former board member of PRC International, a pipeline technology research organization. He has published extensively and holds one patent.

Transmission Pipelines and Land Use
A Risk-Informed Approach

Transmission pipelines make up 20 percent of the 1.8 million total miles of pipelines in the United States and transport virtually all of the nation's natural gas and two-thirds of its petroleum products. In the absence of land use policies, development often may proceed adjacent to pipeline rights-of-way or in the vicinity of active pipelines. Pipeline incidents occur almost daily; most are minor, but a few are not. This report calls on the Office of Pipeline Safety in the U.S. Department of Transportation's Research and Special Programs Administration to work with stakeholders to draft guidance on risk-informed land use for policy makers, planners, local officials, and the public.

Also of Interest

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National Academies Press, ISBN 0-309-08964-6, 112 pages, 6 x 9, paperbound (2003)

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